Quaternary of Northern England

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Chapter 4

The pre-Devensian glacial and interglacial record

INTRODUCTION

D. Huddart

In northern England the major landforms and sediments that can be recognized in the landscape are largely a response to environmental changes that have taken place over the past 150 000 years, through the last interglacial and glacial cycle, into the current interglacial. This is because, with the exception of parts of South Derbyshire and Yorkshire, the region lies wholly within the limits of the Late Devensian glaciation. Consequently, glacial landforms and sediments from this glaciation dominate the region and most of the pre-Devensian deposits have been removed or reworked.

Through all the glacial phases of the Quaternary Period the region was strongly affected by ice from Scottish sources that passed over offshore marine basins, crossed onshore along the Lancashire, Cumbrian, Northumberland, Durham and Yorkshire coasts and coalesced with local ice that radiated from the Pennines, Lake District and Cheviot uplands. The type of Quaternary deposit was determined largely by the region's upland Palaeozoic rocks and surrounding Mesozoic sedimentary basins in the Irish and North Seas. Nevertheless, the cave environment is a favoured location in northern England for the preservation of pre-Devensian deposits and by reference to events that took place in other areas of the country, an extremely fragmented Early and Middle Pleistocene development for the region can be pieced together. This fragmentary evolution is discussed below but the evidence is sparse and the dating almost non-existent.

Traditionally, the Quaternary deposits of Britain have been divided into Lower, Middle and Upper divisions and for convenience of treatment this approach is simplified and maintained here. Deposits of the Lower Quaternary are essentially restricted to East Anglia and comprise marine and terrestrial sediments deposited on the western margin of subsiding North Sea sedimentary basins. Although displaying alternating cold and temperate faunal characteristics they are free of evidence of extensive glaciation. The Middle Quaternary, also exposed mainly in East Anglia, records similar repeated climate changes that include, traditionally, evidence for two extensive phases of glaciation, the Anglian and the Wolstonian cold stages and two intervening interglacial stages, the Hoxnian and Ipswichian. The Upper Quaternary covers the last interglacial–glacial cycle of the Devensian cold stages and the current temperate interglacial stage, the Holocene. Many of the stages in the Lower and Middle Quaternary have not yet been matched to the oxygen isotope stages defined from ocean records. Consequently, traditional stratigraphical stage names and marine oxygen isotope stages (OIS) are used in this discussion of pre-Devensian events in northern England.

THE LOWER QUATERNARY

Probably the earliest terrestrial Quaternary deposit in northern England comes from a cave site in Derbyshire. Victoria Quarry cave at Dove Holes was discovered during quarrying and it contained a series of deposits, now removed, of stratified, yellowish-red clay containing limestone and irregularly distributed bones and teeth, described by Dawkins (1903). He suggested from the weathered state of some of the bones, and possible teeth marks, that the material had accumulated in a hyaena den at a higher level and subsequently had been washed deeper into the cave. Work by Spencer and Melville (1974) on the surviving fauna shows that it contains hyaena (*Crocuta* sp.), sabre-toothed tiger (*Homotherium sainzelli*), gomophothere mastodont (*Anancus arverensis*), extinct elephant (*Archidiskodon meridionalis*), extinct horse (*Equus cf. bressanus*) and a deer (*Dama* sp.). This warm temperate fauna suggests an open grassland. The reassessment rejects hyaena denning as the bone accumulating mechanism. They assigned a Lower Pleistocene (Villafranchian, Plio-Pleistocene transitional faunas in Europe (see Zeuner, 1953 and Bowen, 1978)) age to the fauna, whilst Stuart (1982) noted that the presence of *Anancus arverensis* indicated an age not later than the Bramertonian temperate stage. West (1980b) had added the pre-Pastonian and Bramertonian stages to the climatostratigraphical stages in Britain (compare Table 2.3, Chapter 2) but as Jones and Keen (1993) suggest, the timing of the Bramertonian is both problematical and controversial. It is suggested as a warm temperate stage after the Baventian.

The earliest suggestion for glaciation in northern England is in the Thurnian cold stage (see Table 2.3, Chapter 2). It appears to have had a climatic environment colder than those that currently exist in this country. Jones and

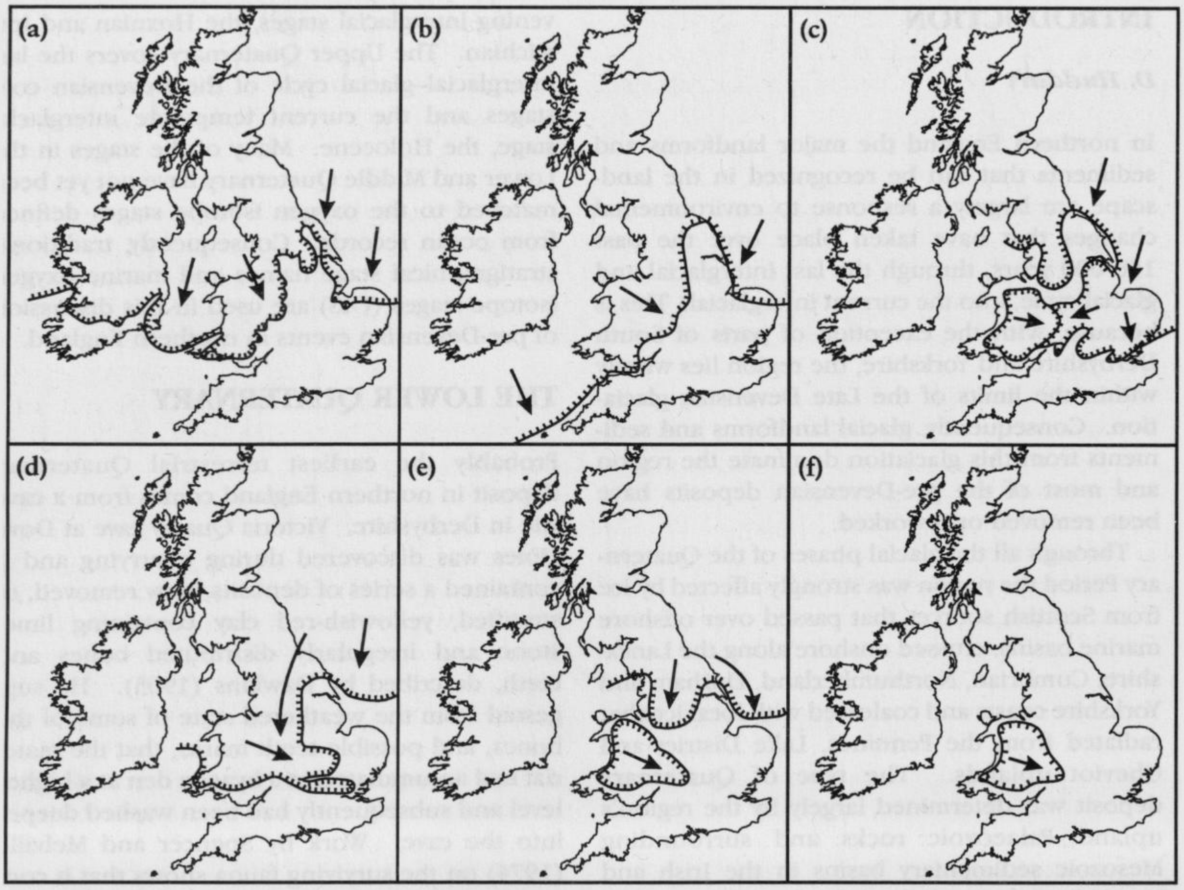

Figure 4.1 Possible ice margins and principal ice movement directions (after Catt, 1981): (a) Devensian; (b) Wolstonian; (c) Anglian; (d) Beestonian; (e) Baventian; (f) another early Quaternary stage.

Keen (1993) suggest that temperatures may have been low enough to allow the accumulation of at least localized ice in the northern and western highland regions of Britain during this phase. However, there is no evidence for this. The ice limits drawn on Catt's (1981) map (Figure 4.1) are nothing more than conjecture, as that author acknowledges, and there is no real evidence for direct glacial deposition.

Baventian cold stage

There is perhaps marginally more evidence for the younger Baventian cold stage in northern England. Catt (1981) considered it possible that ice may have entered the North Sea basin during this phase, possibly for the first time. Certainly there is evidence for low temperatures from the pollen record (Turner, 1975) and Hey (1976, 1980) reported the presence of *Rhaxella* chert likely to be from the Jurassic deposits in eastern Yorkshire as a component of Baventian marine gravel at Easton Bavents. Discussion in Mottram (1999) suggests that the evidence allows only speculation as to the precise provenance and that it is possible that the specimens represent more than one outcrop area, for example offshore Yorkshire and Lincolnshire (Cameron *et al.*, 1992) and the Moray Firth (Andrews *et al.*, 1990). West (1980) cited too the occurrence of metamorphic minerals, with Norway the probable provenance, in Baventian sediments in Suffolk. The likelihood is that these components were brought to Suffolk either by icebergs in a glaciomarine environment or by glacial outwash. The pollen and foraminiferal record had already allowed Funnell and West (1962) to suggest that 'glaciers were present not far from East Anglia'. Scattered remnants of weathered sediment that resembles till in Oxfordshire (Shotton *et al.*, 1980) and Hertfordshire (Catt, 1981; Jones, 1981) may be evidence for Early Pleistocene glacials. Hey (1991) reviews this type of evidence and suggests that although Shotton *et al.*'s (1980) striated clasts in the Northern Drift could have been carried by ice-floes and this would account for the glaciated sand grains of the Kesgrave Formation, the glacial origin is not unequivocal. It does not explain the variations in composition noted by Hey (1986) in the Northern Drift and its supposed downstream equivalents, and it does not explain why the Northern Drift contains very few, highly durable, Palaeozoic clasts from the Midlands. Hey (1991) suggests that the Northern Drift was deposited by a river issuing from an ice-front situated some distance to the north of the present Cotswold scarp. The upper course of such a river might well have been confined largely to Triassic outcrops, and therefore its bedload may have been dominated by Bunter pebbles. Nevertheless its bedload composition might have varied in response to changes both in the ice sheet itself and in the non-glaciated areas drained by its outwash. Erratic content was used by Catt (1982) to imply that residual glacial sediments on the Yorkshire Wolds could be of Baventian age.

Pastonian temperate and Beestonian cold stage stages

There is some evidence from dinoflagellate and pollen and spore data to suggest that the Bridlington Crag along the Yorkshire coast may be of the Pastonian temperate stage (Reid and Downie, 1973; Gibbard *et al.*, 1991). The following Beestonian cold stage, with evidence of ice-wedge casts in river sediments in East Anglia (West, 1980), indicates at least discontinuous permafrost and mean annual temperatures not exceeding 6°C, although there is no evidence of glacial activity in that region. However, the presence of far-travelled, presumably glacially derived, gravels in the Thames river terraces, which may have formed in the Beestonian, has been reported by Green and MacGregor (1980) and glaciers being present in Northern England, Scotland and Wales seems likely. Catt (1981) produced a tentative ice-limit and he suggested that the Northern Drift of Oxfordshire could be the result of a Beestonian glaciation. The lower of two tills in the Kettering and Buckingham areas (Hollingworth and Taylor, 1946; Horton, 1970) may be of equivalent age.

In the central North Sea, glaciomarine sediments were deposited in this phase (Figure 4.2) (Cameron *et al.*, 1987; Long, A.J. *et al.*, 1988). The sediments of the Kesgrave Formation from inland East Anglia were noted earlier and they have been recognized in many localities (Rose and Allen, 1977; Hey, 1980). Many of the members of this Formation were probably deposited in a braided, ancestral Thames under a periglacial climatic regime. As some of the gravels contain Triassic conglomerate clasts derived from the western English Midlands and from North Wales volcanic rock, it seems likely that they were derived from glaciation to the west and north-west (Bowen *et al.*, 1986) and some are likely to be Beestonian in age (Zalasiewicz and Gibbard, 1988).

There has been a detailed interpretation of the Kesgrave Group, the pre-Anglian terraces of the River Thames, in Essex and Suffolk by Whiteman (1992) and Whiteman and Rose (1992). Within this Group, which spans a long time period from the pre-Pastonian to the early Anglian, they recognize ten terraces and a major subdivision into the quartz-rich Sudbury Formation and the flint-diluted Colchester Formation. They believe that the Thames rose in Wales during the deposition of the highest terraces forming the Sudbury Formation and that it had lost its headwaters west of the Cotswolds by the time the Colchester Formation was deposited. Their interpretation implies glaciation in upland Wales, and by implication in northern England, during the pre-Pastonian, and a West Midland glaciation during the deposition of the Waldringfield Member of the Colchester Formation. This suggested to Gibbard *et al.* (1991) that glacial episodes can be taken back to 1.2–1.4 Ma, and quoting Bowen *et al.* (1986) they state 'it appears that the Kesgrave Formation is associated with five glacial events in western Britain between the Baventian and the Cromerian (*sensu stricto*)'.

Recent work has shown that the Pastonian is Early Pleistocene in age and is separated from the Cromerian by a huge time interval (Preece, 2001). It is clear from northern England that we know little from this Lower Quaternary period.

Cromerian temperate stage (Oxygen Isotope Stages 13–21)

The succeeding Cromerian interglacial is possibly marked by deposits in northern England at Blackhall, County Durham that contain plant, molluscan and vertebrate fossils possibly

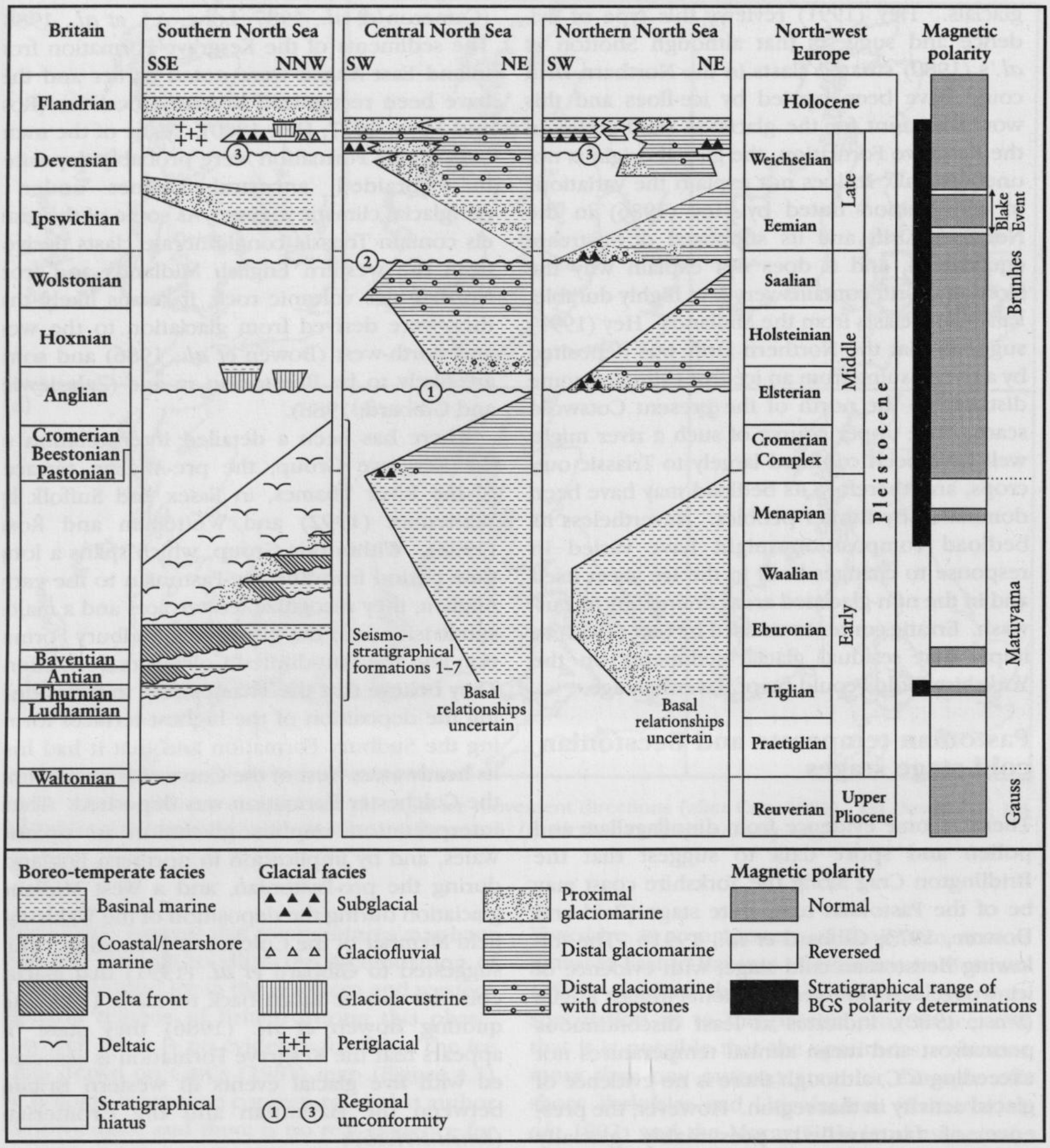

Figure 4.2 Summary of the probable Pleistocene chronostratigraphical ranges of the sedimentary facies represented in the UK sector of the North Sea (after Cameron *et al.*, 1987; Long, A.J. *et al.*, 1988).

representing this warm stage (Kennard and Woodward, 1919, p. 200; Trechmann, 1919; Reid, 1920). It is also worth noting that a water vole, *Mimomys* (Hinton, 1919, p. 201), and an elephant, *Archidiskodon meridionalis* (Andrews, 1919), have been reported from these County Durham fissure deposits, one of which may be Cromerian in age. Both animals have been recorded in Cromerian deposits in the British Isles, with the elephant becoming extinct in the early Middle Pleistocene (Stuart, 1982). There is further discussion of this in the description of the Warren House Gill GCR site. The correlations between the northern England deposits and oxygen isotope stage stratigraphy are given in Table 4.1 from Thomas (1999), where it can be seen that the Blackhall Colliery Formation is categorized as pre-stage 9. In the Derbyshire

Table 4.1 Correlations between northern England and the marine oxygen isotope stratigraphy (after Thomas, 1999).

$\delta^{18}O$	Isle of Man	Lancashire	Cumbria	Yorkshire and Derbyshire	Northumbria	Cheshire and Staffordshire	Shropshire Lowlands
1	**Point of Ayre Formation** Ayre, Cranstal and Ballaquark Farm members; **Bungalow Formation**; **Curragh Formation**	**Lytham Formation**; **Swettenham Formation**	**Solway Formation**; **Grange Formation**; **Blelham Formation**	**Ringingslow Formation**	**Thoraby Formation**	Elmore Member; Fenns Whixall Member	
2	**Ballaugh Formation** Ballacregga, Ballyre, Ballaleigh, Sulby, Ballaugh, Carwyn and Ramsey members; **Snaefell Formation** Druidale, Ballure and Mooar members; **Jurby Formation**; Glen Ballyre Bed; Jurby Head Bed; Ballateare, Ballaquark, Cranstal, Nappin, Phurt and Trunk members; **Orrisdale Formation** Orrisdale Head, Bishop's Court, Ballavarkish, Ballacottier, Kionlough and Dog Mills members; **Shellag Formation** Bride, Crosby, Cronk Ny Laa, Wyllin and Kirk Michael members	**Seacombe Formation**; **Shirdley Hill Formation**; **Kirkham Formation**	**Windermere Formation**; St Bees Head Bed; **Wolf Crags Formation**; **Morecambe Formation**; **Threlkeld Formation** Threlkeld, Lobbs and Mosedale members; **Black Combe Formation** Annaside, Gutterby and St Bees members; **Carlisle Formation** Rose Hill, Holme St Cuthbert and Brunstock members; **Penrith Formation** Baronwood and Eden members; **Irthing Formation** Lanerstock, Brampton and Great Easby members; **Selker Formation**	**Sutton Formation**; **Bingley Bog Formation**; **Escrick Formation**; **Filey Formation**; **Pickering Formation**; **Hemingbrough Formation**	**Bamburgh Formation**; **Bradford Kames Formation**; **Ebchester Formation**; **Linhope Spout Formation**; **Acklington Formation**; **Sunderland Formation** Pelaw, Swaddles Hole, Ryhope, Herrington and Seaham Harbour members; **Wear Formation** Framwellgate, Butterby, Durham and Winch Gill members; **East Durham Formation** Horden, Peterlee and Blackhall members; **Rockcliffe Formation**	**Stockport Formation**	**Shrewsbury Formation**
3				Hartle Dale Bed; Oxbow Bed		**Chelford Formation**	
4			**Luce Bay Formation**	Stump Cross Bed			
5			Scandal Beck Bed				
5e		**Raygill Delf Formation**	**Wigton Formation**; Lindal Cote Bed; Troutbeck Palaeosol	**Alvaston Formation** Elder Bush, Austerfield, Kirkdale and Victoria beds; **Raincliff Formation**	Hutton Henry Bed	Burland Member; Farm Wood Member; Arclid Member	**Four Ashes Formation**
6/8	**Kiondroughad Formation**	**Pilkenzane Formation**	**Thornsgill Formation**	**Bakewell Formation**; **Balby Formation**	**Warren House Formation**	**Oakwood Formation** Lapwing Bed	
7/9	**Ayre Formation**				**Easington Formation**		
Pre-9	**Isle of Man Formation**			**Dove Hole Formation**	**Blackhall Colliery Formation**		
9						Trysull Member	
10							
11							
12						**Seisdon Formation**	
13–16							

caves some of the earliest evidence comes from high-level systems such as Water Icicle Close Cave above the Lathkill valley, where there is speleothem development associated with the Cromerian (Burek, 1991) and the Group V system from Derbyshire (Ford *et al.*, 1983) dates to 350 Ma, which also suggests the Cromerian warm stage.

However, Preece (2001) suggests that the single Cromerian interglacial is an oversimplification and that the molluscan evidence points to as many as five distinct stages within the 'Cromerian Complex'. Similarly Stuart and Lister (2001) present mammalian evidence for an additional temperate stage in the early Middle Pleistocene, distinct from that reconstructed from the West Runton, Cromerian type site. They suggest that sites of 'Cromerian Complex' age may be coarsely grouped into those containing the ancestral water vole, *Mimomys savini*, or those containing its probable descendent, *Arvicola terrestris cantiera*. They propose that as many as four separate temperate episodes may be represented by sites with *Mimomys*, whereas at least two distinct temperate episodes are represented by sites with Arvicola. This complexity again highlights how little we know of this 'Cromerian Complex' in northern England.

Conclusion

The evidence for the Quaternary development of northern England between the Late Pliocene and Cromerian warm phase is fragmentary. In the warm temperate stages speleothem growth took place in the high-level cave systems in Derbyshire and the Yorkshire Dales. During the colder phases there is certainly circumstantial evidence for ice being present in the uplands of northern England, Wales and Scotland, although all the evidence is indirect. The scale and size of such ice masses and the effects that they undoubtedly had on the landscape can only be conjectural given the current evidence. The relationship of most of these stages to the marine oxygen isotope record also is debatable.

THE MIDDLE QUATERNARY

This period includes the traditional Anglian cold stage, Hoxnian temperate stage, Wolstonian cold stage and the last interglacial Ipswichian temperate stage and covers the oxygen isotope stages 12 through to 5e. The major difficulty is correlating the cold phases, their deposits and landforms and deciding on the status of the various postulated cold stages.

Oxygen Isotope Stage 12: Anglian cold stage

This cold stage has been reviewed by Jones and Keen (1993). Most of the evidence has been obtained in East Anglia and successions in other parts of the country traditionally have been thought to contain little or no representation of this stage. The record of glacial sediments in East Anglia that had been attributed to two time-independent glacials (Mitchell *et al.*, 1973) became simplified by suggesting that most of the pre-Devensian sediments were part of the Anglian cold stage (Bristow and Cox, 1973) and dated to Oxygen Isotope Stage 12 (OIS 12) of the marine sequence. A by-product of this has been the questionable status of the Wolstonian glaciation formally designated as later in time (Mitchell *et al.*, 1973), and Bowen (1978) has suggested that the type locality at Wolston was unrelated to any interglacial marker horizon, the fundamental basis of the 1973 classification. Since then a variety of evidence has been advanced to show that the Wolstonian type site proposed as the post-Hoxnian, pre-Ipswichian glaciation is pre-Hoxnian and is correlated with the Anglian Stage of East Anglia (Perrin *et al.*, 1979; Sumbler, 1983a, b; Maddy *et al.*, 1991). The discovery of organic deposits correlated with the Hoxnian on the surface of the Wolstonian deposits at Froghall appears to have settled this controversy (Keen *et al.*, 1997; Maddy, 1997). At present the only lithostratigraphical evidence adduced to support a post-Hoxnian but pre-Ipswichian glaciation of East Anglia comes from the Nar valley in Norfolk, where gravels interpreted as outwash overlie the marine clays of the Nar Valley Formation, but no contemporaneous till has been identified (Gibbard *et al.*, 1991, 1992). Increasingly all the glacial sediments in Britain are being attributed to the Devensian or the Anglian. Hence the precise position of some of the older glacial deposits in northern England that are stratigraphically below interglacial deposits earlier than Holocene can be seen as either Anglian or Wolstonian in age.

How did this position develop? As the primary mapping of the Quaternary drifts proceeded during the nineteenth century, the Newer Drift, associated with the Devensian glacial, and the Older Drift, which was associated with more than one earlier glacial, were distinguished. The division was based partly on geomorphological criteria, as the Newer Drift retained fresh, depositional landforms, such as eskers, kames and drumlins whereas the Older Drift typically did not, the constructional relief having been smoothed by erosion and hill-slope processes because of the longer time period since formation. The Older Drift was also generally found on plateaux, dissected by later erosion, with later drift-free valleys cut into the original drift cover. In contrast, the Newer Drift was found most often in valleys and the drainage network had not had time to become integrated and rivers flowed around the depositional landforms. However, a major problem is that an advancing ice sheet erodes and incorporates older stratigraphical evidence as it moves forward. This means that the Anglian ice sheets completely covered any earlier advances, leaving only chance evidence of their occurrence that is difficult to interpret. It can be assumed too that the records of any later glacial advances in OIS 10, 8, 6 and 4 of the marine record were reworked, or hidden by, the Devensian (OIS 2) advance. Over western and central Europe, three separate glaciations have been recognized, with a possible fourth. For example, in The Netherlands three glacials are readily recognized because the successive Elster (OIS 12), Saale (OIS 10) and Weichselian (OIS 2) ice advances were each slightly smaller in extent, leaving a marginal zone of sediments, together with intervening interglacial beds. The extent of the Scandinavian ice sheet was about 98%, 100% and 85% by relative area in these three major glacials, and hence the Saalian ice overran the Elsterian ice along most of the southern limit of glaciation. There seems no doubt that the Anglian and Devensian in Britain are correlated with the Elsterian and Weichselian phases, which means that the traditional British Wolstonian must coincide with the most extensive glaciation in continental Europe, the Saale. At one stage the uppermost chalky till of East Anglia was correlated with the Saalian glacial, but a reconsideration of the East Anglian stratigraphy has led to the almost universal adoption of a monoglacial chronology, with the North Sea (Cromer Till) Formation and Anglian Till (Chalky Boulder Clay) attributed to two sequential Anglian advances from different directions. Farther north in eastern England, remnants of possible Anglian glacial deposits have been noted on the summit areas of the Yorkshire Wolds, although they could be Baventian in age as noted earlier (Catt, 1982), on the North Yorkshire Moors (Call, 1987a), in the southern part of the Vale of York in the Selby and Doncaster areas (Gaunt, 1981) and on the Pennine slopes east of Leeds, Wakefield, Sheffield and Chesterfield. In the latter area patches of grey till and gravel that contain erratics of Carboniferous sandstone, limestone, chert, coal, vein quartz, Permian limestone and occasional Lake District rocks were mapped by the [British] Geological Survey, and it was realized for over a century (Green *et al.*, 1878) that the entire region had been covered by ice containing Lake District and Pennine erratics. This ice was earlier than the last glacial because the erratics extend well outside the Devensian limit (Gaunt, 1981) and usually are at greater heights than the Devensian till in the Vale of York, reaching over 100 m OD near Leeds, over 200 m OD near Sheffield and over 300 m near Chesterfield. However, there is no evidence that the ice surmounted the 400 m cuesta around the northern and eastern flanks of the Peak District. If these uplands were ice free, glacial lakes may have existed and laminated clay is intimately associated with glacial deposits near Barnsley (Green et *al.*,1878), near Rothwell (Gilligan, 1918), at Balby and on top of Brayton Barff (Catt, 1991b). Gaunt (1981), on the basis of till-fabric analyses and erratic provenance (Figure 4.3) suggested the initial ice movement was via Stainmore and the Vale of York, as favoured by Carter (1905) and Harmer (1928).

In the southern Vale of York area, however, Catt (1991b) suggested that the various tills beyond the Devensian ice limit were Wolstonian in age. These tills lie rather higher than the adjacent Devensian tills and include occurrences at Bawtry (Gaunt *et al.*, 1972), at Holme upon Spalding Moor and perhaps the large erratic (over 100 m long and 4 m thick) of Cave Oolite, which overlies chalky gravel with far-travelled erratics at 50 m OD near South Cave (Stather, 1922). Deep, narrow-sided valleys near Doncaster are partly filled with over-consolidated clays, often covered with grey till (Gaunt, 1981) and are interpreted as subglacial tunnel valleys eroded beneath the pre-Devensian Vale of York glacier. So there seems the possibility here that these deposits south of the Devensian limits could be either Wolstonian or Anglian. Catt (1991b) is adamant, however, that the erratics

Figure 4.3 Evidence of the direction of initial ice advance in the 'Older' glacial stage in part of Yorkshire after Gaunt (1981) (Wolstonian or Anglian? – see text).

and heavy minerals in deposits high on the Yorkshire Wolds must be pre-Wolstonian and therefore likely to be Anglian.

Scattered till deposits have been recorded in the Peak District (Stevenson and Gaunt, 1971). Those that are deeply weathered and at higher altitudes were deposited probably during the Anglian (Briggs and Burek, 1985; Burek, 1991). These highly weathered, complex till deposits, scattered over the Brassington Formation sand pits at heights of 330–360 m OD, lie unconformably over limestone collapse structures and are laterally limited. Limited fabric analyses indicate a possible eastern derivation for these cherty tills (Burek, 1991). At the Bees Nest pit a silty, roughly stratified, cherty deposit with scattered pebbles overlying the Mio-Pliocene sands and clays was interpreted as a soliflucted till because of the presence of rare, far-travelled erratics (Ford, 1972). Scattered erratics up to 396.5 m OD (Dale, 1900) also have been suggested as being deposited from an Anglian ice source (Burek, 1991). In the limestone areas these may be explained by intense post-depositional decalcification of an originally thicker till and the transport of the finer-grained sediments into the cave systems. In the Dark Peak, however, the evidence for weathering is less convincing and the suggestion is that the tills here were never thick or continuous. Briggs and Burek (1985) suggest that the Peak District was affected by relatively clean, cold-based ice which introduced little extraneous debris and carried out limited erosion. There is, however, a clear difference between the upper and lower tills in X-ray diffraction analyses (Burek, 1978; Briggs and Burek, 1985).

The tills at lower altitudes show decalcification in their upper layers, comprise a fine-grained, brown-grey clay matrix, which supports dominantly local clasts such as limestone, dolerite, basalt and sandstone, but with smaller quantities of far-travelled rocks, including granites from the Lake District and Scotland. The till distribution is impersistent and restricted, with the majority of the deposits covering bench-like, dissected surfaces. Striations on the bedrock, fabric analyses and stone counts all indicate ice movement from the NNW, and the implication is that ice advanced into the Peak District across the Dove Holes col at 310 m OD (Briggs and Burek, 1985). The stratotype for this Bakewell Formation is the Shining Bank Quarry (Thomas, 1999).

The continental sequence of Saalian age includes three tills, which are often attributed to three separate ice advances: the Warthe, Drenthe and Fuhne. The Warthe, the youngest, tends to be found low in the landscape, whereas the earlier two phases deposited sediments that have been dissected, like the Elster, and generally occupy plateau locations. Thus it is feasible that two or more morphologically separable Wolstonian sequences could occur in Britain. One could be difficult to separate from the Devensian, such as the Vale of York glacial tills and buried channels, whereas the other could easily be confused with the Anglian, such as the type Wolstonian of the East Midlands. However, credible evidence for the missing Wolstonian Stage has yet to be found (Ehlers *et al.*, 1991), although it seems likely that some of the deposits in northern England, in Durham, Derbyshire, Yorkshire and north Lincolnshire, are from this stage.

It has been demonstrated that the deposits of the type site Wolstonian in the Midlands are of Anglian and pre-Anglian age (Rose, 1987, 1991), although there is a some evidence that a post-Anglian, pre-Devensian glaciation did indeed affect the Midlands (Maddy *et al.*, 1991). This suggests that pre-Holocene lake basins, resting on till and yielding pollen sequences may well be of different ages. At the same time, it seems possible that two episodes, each with a 'Hoxnian-type' pollen signature are recorded from the Middle Pleistocene (Roe, 1995; Keen *et al.*, 1997). Thomas (2001) reviews the evidence for interglacial deposits in the Midlands that occur in lithostratigraphical contexts comparable with Hoxnian sites in East Anglia. She concludes that the palynology of lake sequences in the Midlands shows strong similarities to comparable records from East Anglia, suggesting that all represent lakes formed after the same Anglian glacial and therefore record sediments of the same Hoxnian interglacial. Despite these complexities, which are still not fully resolved, it is assumed in this book that there is evidence for a Wolstonian age glacial in northern England, although demonstrating that age is difficult.

Oxygen Isotope Stage 9: the Hoxnian temperate stage

This interglacial has been defined by West (1956) based on the type site at Hoxne (Suffolk), where lacustrine sediments overlie Lowestoft Till (Anglian). It is now correlated with OIS 9 about 338 000–302 000 years Before Present (BP), although there have been a number of correlation and dating problems (Jones and Keen, 1993). A number of other occurrences of Hoxnian deposits have been described from localities in East Anglia, the Thames Valley and the Midlands, and several locations from northern England appear to show development stages during this interglacial. At Kirmington close to the eastern foot of the Lincolnshire Wolds, Watts (1959) described peat associated with estuarine sediments at 27 m OD from this interglacial. Shingle above the silts was probably deposited as a beach during the highest stand of the sea in the later part of the interglacial (Catt, 1977b). At Speeton, south of Filey on the Yorkshire coast, estuarine silt and sand exposed at about 30 m OD has a temperate fauna and is overlain by till of probable Wolstonian age. Catt and Penny (1966) and Penny and Catt (1972) have suggested that the altitude and stratigraphical relationships of these estuarine deposits are consistent with a Hoxnian age, although palynological data reported by West (1969) are more indicative of Ipswichian vegetation. Wilson (1991) has identified a comparable pollen assemblage to that obtained by West, but amino-acid ratios of *Macoma balthica* shells from the deposit suggest that it accumulated during OIS 7. This site is discussed more fully in the site report for Speeton (this chapter). There may also be palaeosol sites partly related to this interglacial in the North Yorkshire Moors (Bullock *et al.*, 1973) and in the north-eastern Lake District (Boardman, 1985c), as soil may be polycyclic and contain evidence of more than one climatic episode. These problems are discussed further in the Harwood Dale Moor and Thornsgill site reports (this chapter). In the Peak District, the warm, moist conditions of this interglacial cemented screes, tufas formed and speleothem development was active in the high caves at Castleton (Burek, 1991). The Hathersage river terrace was formed during the extensive in-situ weathering and soil formation of this stage, when the rivers Derwent and Wye were incised to this level. Ford (1985) has also provided evidence for substantial cave development during and before the Hoxnian through isotopic dating of the Castleton speleothems.

Oxygen Isotope Stages 6–8: the Wolstonian cold stage

Mitchell *et al.* (1973) assigned the period between the Hoxnian and the Ipswichian interglacials to the Wolstonian cold stage, but there has been much discussion as to its status in Britain, as noted earlier. There is also evidence available for another interglacial between those of the Hoxnian and Ipswichian, and for an associated cold stage, either from a reappraisal of known sites, such as Trafalgar Square, Ilford, Aveley, Portland, Minchin Hole, or new sites, such as Stanton Harcourt and Marsworth (Jones and Keen, 1993). In northern England, sites with supposed Wolstonian sediments are usually problematic and the sediments could be assigned to this cold stage or an earlier one. So, for example, the Oakwood Till at Chelford (Worsley, 1978), if not Early Devensian (Worsley *et al.* 1983), could be Wolstonian or Anglian (see the site report for Chelford, Chapter 5, for further discussion). The same applies to the thin till deposit at the base of the Burland borehole, Cheshire (Bonny *et al.*, 1986). There has already been a discussion on the age of the Lincolnshire tills and in eastern Yorkshire the Basement Till observed at several localities between Filey Brigg to Spurn Point, and which occurs below an Ipswichian raised beach at Sewerby and above the Speeton Shell Bed in Filey Bay has been referred to the Wolstonian. Isolated patches of deeply weathered glacial material on the Yorkshire Wolds and North Yorkshire Moors may have been deposited during the Wolstonian, and the landforms and sediments in the southern Vale of York may be from this cold phase. Some of the glacial deposits in the area around East Retford, Worksop and Gainsborough (Smith, E.G. *et al.*, 1973) and in the Sheffield (Eden *et al.*, 1957) and Chesterfield areas (Smith *et al.*, 1967) could date from this time. They have been referred to the Balby Formation by Thomas (1999) and described as decalcified till containing local rock types and Lake District erratics. Tills in the Wye, Derwent and Manifold valleys of the Peak District seem to be Wolstonian (see earlier) and the Derbyshire Derwent underwent a glacial diversion (Straw, 1968b). The till below presumed Ipswichian deposits at Scandal Beck in the north-eastern Howgill Fells (Carter *et al.*, 1978) is presumed to be Wolstonian (see the site report for Scandal Beck, this chapter, for further detail). In the north-east Lake District, pre-Devensian glacial sediments are underlain by palaeosol features likely to have been developed in three temperate episodes (Boardman, 1985c). The older fill could be Anglian or Wolstonian in age (see further discussion in the site report for Thornsgill and Mosedale, this chapter). The basal till in the Low Furness region may also belong to this stage (Huddart *et al.*, 1977; Tooley, 1977) as does the Warren House Till of the Durham coast (Trechmann, 1915; Francis, 1970). Around the fringes of the Lake District the oldest known glacial deposits are the scattered till units deposited from the 'First' or 'Early Scottish' glaciation (Trotter and Hollingworth, 1932; Huddart, 1970, 1971a). These have been recognized at Willowford in the Irthing valley (Trotter, 1929), in the Wiza Beck valley (Eastwood *et al.*, 1968), Gillcambon Beck on the fringes of Greystoke Forest, along with a lower till below a drumlinized till and disturbed silts and clays seen in M6 motorway sections at St. Brelades in the Petteril valley (Huddart, 1970) and the lower till in the Derwent valley. Nirex (1997b) and Akhurst *et al.* (1997) describe sporadic deposits of weathered brown, sandy diamicton of the Drigg Till Formation in boreholes in the Drigg area and other pockets of weathered, basal diamicton in a river cliff of the River Calder. In Edenside a small percentage of Scottish granite erratics have been noted in the Main Glaciation (Devensian) drift by Trotter (1929), Huddart (1971b) and Letzer (1981), and as it is considered that the ice movement was from the south to north in Edenside at this time, these Scottish erratics must have been derived from an earlier Scottish ice advance. It was considered that these scattered examples of early glacial activity could relate either to Saalian (Wolstonian) ice, or to ice advance at the beginning of the last glacial period, when presumably an ice sheet in Scotland would form earlier than in the Lake District (Huddart, 1971b). However, see the discussion of the possibility of an Early Devensian glacial in Chapter 5. As with so many of these types of 'lower' tills the exact chronology is speculative. This too is the case in the western Pennines, where there is little evidence for pre-Devensian till except for some weathered till, 25 m thick, preserved in a col at Pilkenzane, Longdendale (Johnson and Walthall, 1979).

The central North Sea adjacent to northern England has produced evidence for Wolstonian activity (Cameron *et al.*, 1987). Valleys cut during the Anglian continued to be infilled, mainly with glaciomarine sediments. In the late Wolstonian there was a major erosional episode, with a new valley system running mainly north–south, probably incised by glacial meltwater. The offshore sequence has suggested to Cameron *et al.* (1987) and Long, D.C. *et al.* (1988) that terrestrial ice did not move far out into the North Sea and that it was not in contact with Scandinavian ice.

In-situ flowstone obtained from within sand and silts at Robin Hood's Cave, Cresswell, south-east Derbyshire has been dated to about 165 ka by uranium-series dating (Rowe and Atkinson, 1985). The palynology of the sequence (Coles *et al.*, 1985) suggests a vegetation that changed from grassland to open deciduous woodland, subsequently reverting to steppe and tundra. It was considered that it was a temperate equivalent to that identified at Marsworth, with the date for the latter being obtained from a tufa (Green *et al.*, 1984). There have been many archaeological and palaeontological finds from Robin Hood's Cave, but the initial excavations in the western chamber reported by Mello (1875, 1877) and Dawkins (1876) seem to have been haphazard and marred by considerable confusion over the nature of some of the finds. However, an archaeological sequence of a lower assemblage of Middle Palaeolithic artefacts and an upper assemblage of Upper Palaeolithic artefacts was revealed. There was an extensive assemblage of vertebrate remains reported, including hyaena, bison, woolly rhinoceros, horse, dirk-toothed cat and reindeer. Knowledge of the remains from the rear of this cave (Laing, 1889) is limited but tantalizing, and includes finds of hippopotamus. Other parts of the cave have yielded human remains and Acheulian artefacts, but all these finds have been lost.

Conclusion

The probable geological succession in East Anglia for the Hoxnian to the Ipswichian is given in Table 4.2. This revised sequence now incorporates two temperate episodes (Wolstonian 1–2 and Ilfordian) separated by three colder intervals (Wolstonian 1, 2 and 3), with the glacial in Wolstonian 2 and intense periglaciation in Wolstonian 3. Uranium-series dates defining phases of speleothem growth in the Craven District cave systems (Gascoyne *et al.*, 1983) have assisted in refining this chronology. Mineral precipitation was profuse during the periods 90–135 ka and 170–350 ka but ceased during the period 140–160 ka and was reduced about 260 ka. The temperate conditions required for speleothem growth from 170–350 ka have been equated with OIS 7 and 9. The period of zero growth has been assigned to OIS 6 (Wolstonian cold stage) and that of diminished accumulation probably equates to OIS 8.

Table 4.2 Summary of the probable Quaternary sequence in East Anglia from the Hoxnian to the Ipswichian (after Wymer, 1985).

Stage	Years (BP)	Sea level
	75 000	
Ipswichian		High 6–8 metres OD
	128 000	
Wolstonian 3		Low
	195 000	
Ilfordian		High 15 metres OD
	240 000	
Wolstonian 2		Low
	297 000	
Wolstonian 1/2		
	330 000	
Wolstonian 1		
	367 000	
Hoxnian		High 20 metres OD
	400 000	

This period again shows a complicated picture of climatic change and there are major difficulties in correlating the limited successions that are available. There have been major problems associated with the status of the Wolstonian glacial and the orthodox Pleistocene succession in Britain (Mitchell *et al.*, 1973) has required change, with many more climate events present than at first thought (Bowen, 1999).

THE UPPER QUATERNARY

Oxygen Isotope Stage 5e: the Ipswichian temperate stage

This interglacial is dated between 135 and 115 ka, when the interglacial climate was thought to be at its warmest, and it is correlated with marine OIS 5e. From 115 ka onwards the climate began to deteriorate towards the next glacial. There are sites from most parts of the country, although most are in the Midlands and East Anglia, outside the limits of the last glacial, in river valley locations where there was marked river alluviation in this period. Nevertheless, there are some sites ascribed to this interglacial in northern England, although no well-defined, geochronologically constrained unit is known (Thomas, 1999). However, there are mammal bones in limestone fissures, organic muds and palaeosols, cave deposits, river terrace deposits and estuarine sediments and peats incorporated in till from this region that are suggested as Ipswichian. As usual there are problems of correlation because the records are fragmentary and no site extends throughout all the interglacial's sub-stages. There have also been issues as to whether some of the deposits should be assigned to this interglacial, or to an earlier post-Hoxnian temperate stage.

At the Devensian stratotype locality at Four Ashes (see site report, Chapter 5), near Wolverhampton, basal organic sediment in a bedrock hollow has yielded *Taxus*, *Ilex* and *Alnus* macrofossils (Morgan, A.V., 1973) and a pollen assemblage in which *Alnus* and *Quercus* dominate. The postulated Ipswichian age has been confirmed on palynological criteria by Andrew and West (1977), who have suggested reference to Zone 11b of this interglacial. Although a sparse insect fauna occurs in these deposits, it is not diagnostic of the climatic environment (Morgan, A., 1973). The Arclid Member, which is a complex organic-rich sand succession proved in a borehole, originally was thought to be part of the Farm Wood Member peat (Worsley, 1991b) and a probable early Devensian interstadial deposit, but pollen analysis on organic detritus associated with a molar of *Mammathus* has suggested an Ipswichian age (Worsley, 1992).

At Austerfield, in southern Yorkshire, sand and gravel deposited by an ancestral River Idle contains an organic silt bed (Gaunt *et al.*, 1972). Palaeobotanical investigation has demonstrated a single biozone representing mixed-deciduous forest, including *Acer*, *Alnus*, *Pinus* and *Carpinus*, which is probably of late-temperate Ipswichian age. Insect, pollen and macrofossils showed that in Zone 111 times a marshbound lake was surrounded by the woodland in a climate at least as warm as at present. The insect fauna includes *Bembidion elongatum*, *Bothrideres contractus*, *Brachytemnus submuricatus* and *Scolytus carpini* (which exists largely on *Carpinus*), all of which are now extinct in Britain and possess ranges in southern and central Europe. The presence of a lake at about 4 m OD on a contemporaneous floodplain implies that the drainage base level, in effect sea level, was close to OD (Gaunt, 1981). At Langham, near Goole, Ipswichian Zone 11b deposits occur as low as –12 m OD (Gaunt *et al.*, 1974) and show that, early in the interglacial, rivers had incised courses to considerable depths in response to a sea level still eustatically depressed from the preceding glaciation. Pollen, macrofossils and dinoflagellate cysts in clays, sands and gravels between –12 m and –6 m OD show that, as sea level rose in Ipswichian 11b times, estuarine sediments were forming in an area containing pine and oak woodland. At Westfield Farm, Amthorpe a thin clay contains pollen, plant debris and dinoflagellate cysts which show that at the junction with Zones 111 and 1V, estuarine sediments were forming with sea level at, or slightly above OD in an area containing a pine-rich woodland. The dinoflagellate cysts at Langham and Westfield Farm are dominated by *Spiniferites* species, whereas at Langham, *Lingulodinium machaerophorum*, tolerant of weakly saline conditions, has been recorded. The assemblage indicates an estuarine environment in a cool-temperate climate, not dissimilar to that of the sea around Britain today. West (1969) has suggested that a mixed-oak forest pollen assemblage obtained from the Speeton Shell Bed in Filey Bay is analogous to that characteristic of Zone 11f of the Ipswichian (see site report for Speeton, this chapter, for further discussion.)

At Bielsbeck, near Market Weighton, a Pleistocene faunal assemblage that contains *Palaeoloxodon antiquus*, *Stephanorhinus hemitoechus* and *Equus* but lacks hippopotamus (Stather, 1910; de Boer *et al.*, 1958) has been re-evaluated recently by Schreve (1997, 1999) and Schreve and Bridgland (in press). It is now considered to be most consistent with the later part of the OIS 7 interglacial, possibly Sub-stage 7a. The mammalian fauna also includes wolf, brown bear, lion, woolly mammoth, red and roe deer, aurochs, bison and an indeterminate elephant. This fauna indicates both open grassland and woodland habitats. The molluscan list includes several thermophiles that suggest fully temperate conditions. The mammalian fauna is very similar to that from the upper part of the sequence at Aveley (Essex), the Uphall Pit at Ilford and Brundon, all of which have been correlated with OIS 7 (Bowen *et al.*, 1989; Bridgland, 1994; Schreve, 1997). The key factor is the co-occurrence of *P. antiquus* with *Mammathus primigenius*, a combination unknown from any other interglacial. Schreve (2001) correlates the Bielsbeck assemblage and similar assemblages at Hindlow Cave, Derbyshire (Schreve, 1997) and Pontnewydd Cave, Clwyd (Green, 1984) with the Sandy Lane Mammalian Assemblage Zone of the OIS Stage 7 interglacial and separate from the Ipswichian Hippopotamus faunas of Sub-stage 5e.

Sites close to Bielsbeck at North Cliffe and Mott's Field (South Cliffe) have yielded mammalian fauna comparable to the original site and led Schreve and Bridgland (in press) and

Schreve (1999) to suggest that the sediments are probably lateral equivalents. However, remains of *M. primigenius* found in two adjacent pits on Galley Moor, 3.2 km north-west of Bielsbeck and some associated organic material have yielded ^{14}C dates of 47 000 and 46 000 ± 2300 years BP respectively (Halkon, 1999), so whether they are related to the Bielsbeck assemblage is debatable.

In the Peak District, travertine from Elder Bush Cave in the Manifold valley contains leaf impressions of *Acer monspessulanum* (Montpelier maple) and *Corylus avellana* (hazel). These were in association with a fauna that included lion, hyaena, wolf, giant deer, hare, large bison and hippopotamus. This evidence suggests fairly dry, temperate to warm conditions (Bramwell, 1964). A similar Ipswichian fauna has been reported from Hoe Grange Quarry Cave, Longcliffe (Bemrose and Newton, 1905), although this is now completely quarried away. Other possible Ipswichian cave sites remain unpublished, such as that at Etches Cave, East Sterndale (Coles, 1985) and further north in the Pennines in a limestone fissure at Raygill Delf, a mammalian fauna (Miall, 1880) has been identified as Ipswichian by Earp *et al.* (1961).

At the Boulton Moor GCR site, the stratotype of the Alvaston Formation (Thomas, 1999), gravels of the Beeston Terrace of the River Derwent contain a mammalian fauna correlated with the Ipswichian (Jones and Stanley, 1974) (see GCR site report in Allen *et al.*, in press). There are probably equivalent deposits at Allenton (Godwin, 1975) and at Leeds, which contain hippopotamus (Edwards *et al.*, 1950). At the latter location a large hippopotamus bone assemblage and teeth had been discovered in a clay pit at Wortley (Denny, 1854a, b). The problems of dating the museum specimens were discussed subsequently by Harkness *et al.* (1977), but an indefinite date of over 40 000 radiocarbon years from a large molar suggested an Ipswichian age for the bones and teeth. However, although three other bones gave dates of about 31 000 radiocarbon years and are thought to be contaminated, the deposits in which these bones were found are considered to be glaciofluvial and of Devensian age.

Kirkdale Cave, north of Kirkbymoorside (North Yorkshire), first investigated by Buckland (1822) and reported on by Boylan (1972, 1977a), has produced a typical Ipswichian climatic optimum fauna. So has the Lower Cave Earth from Victoria Cave, Settle (Boylan, 1977b), but the exact provenance of a hand-axe from this deposit in relation to dated flowstone (uranium-series dates ranging from 135 to 114 ka) there is unknown. From this cave too, flowstones covering a characteristic Ipswichian mammal fauna have been dated to 120 ± 6 ka and the animal remains correlated to OIS 5e (Gascoyne *et al.*, 1981). Other flowstone dates from the Craven District (Gascoyne *et al.*, 1983) indicate a period of abundant speleothem growth between 90–135 ka and the Ipswichian stage is defined as occurring between 135 and 115 ka.

Interglacial marine deposits at Sewerby show a typical Ipswichian faunal assemblage (see site report for Sewerby, this chapter) with the marine beach and an associated buried cliff associated with the Ipswichian sea level traced along the western side of Holderness and the Lincolnshire Marsh (Catt, 1977a, 1987a). This has been correlated with temperate marine faunas at Shippersea Bay, Easington (see site report for Shippersea Bay, this chapter) from the raised beach at over 30 m above modern sea level, but this height is difficult to reconcile with Sewerby. It has been claimed by Bowen *et al.* (1991) that the Easington beach dates from OIS 7 based on amino-acid analysis of the molluscs. In fact two populations of shells were identified based on amino acid ratio data, an older one with a mean D/L ratio of 0.228 ± 0.12 and a younger one with a ratio of 0.174 ± 0.01. The older population was interpreted as reworked from deposits dating from a previous high sea-level phase, which they attributed to OIS 9. The younger population indigenous to the Easington beach was indicative of OIS 7.

A similar problem occurs around Morecambe Bay where wave-cut notches and caves in Carboniferous Limestone at locations such as Edgar's Arch and Kirkhead Cave at heights of about 4.9–6.4 m OD might demonstrate Ipswichian marine erosion (Tooley, 1977), but it also has been suggested that they are Hoxnian or older (Tooley, 1982, 1985). At Whitbarrow there are notches at +30 m OD and below the cavern on Kirkhead Hill and on Warton Crag there are notches at +15 m and +30 m OD (Ashmead, 1974; Tooley, 1985). It seems possible that we could have a sequence of OIS 9 and 7 wave erosion features around the margins of Morecambe Bay. However, it also has been suggested that the so-called 'sea caves' are phreatic and unrelated to any contemporary sea level, that their heights are not as reported by Ashmead (1974) and that the features often reported as marine-cut notches are the result of glacial plucking of weak bedding planes in the limestone (Gale, 1981).

Farther to the north in Furness, Rose and Dunham (1977) described unconfirmed reports of peat beneath till from a borehole at North Scale (Walney) and at Lindal-in-Furness, where, from a series of shafts at Lindal Cotes and Crossgates, a peaty deposit, up to 8 m thick, containing insects, leaves and fruit receptacles of beech, and diatoms, and overlain by up to 30 m of till was described by Bolton (1862) and Hodgson (1862). However, the latter author doubted whether the material was interglacial and believed it to be a recent infilling of a subterranean drainage course. Later Kendall (1881) described an extensive organic deposit, south-west of Lindal, from numerous boreholes, which proved a peaty deposit up to 7 m thick that was overlain by up to 30 m of till, sand and clay. An attempt to relocate this deposit by an IGS borehole proved negative (Anon.,1972). These Furness peats have been suggested as being Ipswichian in age by Huddart *et al*. (1977) and Thomas (1999). Hodgson (1862) also described a griked limestone surface near Ulverston, capped by up to 3.5 m of till, but with the grikes filled with a stone-free tenacious yellow clay, which could be a weathering horizon. No Ipswichian deposits have been reported from the recent Nirex (1997a, b) investigations, but it is assumed that the presumed marine deposits from Wigton are Ipswichian in age. Here a borehole proved lenses of drab clay containing *Turritella comminus* Risso, foraminifera and ostracods, beneath gravel and till (Eastwood *et al*., 1968). However, there were gaps in the cores, both above the clay and between the clay and the underlying Stanwix Shales, and it is possible that the clay was not *in situ* and was an erratic within the till. It also is possible that the unit could be evidence for a mid-Devensian marine sequence as reported from the Drigg area (Eaton and Curtis, 1995; Huddart, 1997).

Probable Ipswichian interglacial weathering profiles have been recognized in plateau areas not glaciated during the Devensian, such as parts of the North Yorkshire Moors (see site report for Harwood Dale Moor, this chapter) and the Pennines and it is suggested that at least part of the weathering that contributed to the Troutbeck Palaeosol in the Lake District (see site report for Thornsgill and Mosedale, this chapter) took place in this interglacial. There are two other undoubted Ipswichian peat deposits in northern England, a raft within Devensian till at Hutton Henry in County Durham (Beaumont *et al*., 1969) and a glaciotectonized peat succession at Scandal Beck (Carter *et al*., 1978; Letzer, 1978, 1981; see site report for Scandal Beck, this chapter).

Conclusion

Thus in northern England the Ipswichian Stage record is fragmentary with historical records of sites that cannot be, or recently have not been relocated, and with sites that are likely to have been incorporated into Devensian till. The best preserved records appear to be in caves. There is controversy over the age of some suggested Ipswichian deposits, with correlation to both OIS 5e and OIS 7.

THORNSGILL AND MOSEDALE (NY 355 235, NY 381 242)

J. Boardman

Introduction

Thornsgill and Mosedale Beck, in Cumbria, are north-flowing tributary streams of the River Glenderamackin (Figure 4.4). They incise up to 30 m into Quaternary deposits and Skiddaw Slate bedrock and occupy the southern flank of a broad glaciated trough, the Vale of Threlkeld, along which ice moved from west to east during the Devensian glaciation. In the region of Mosedale ice was moving to the north-east (Figure 4.5).

Although no site displays the full stratigraphy, numerous exposures in Thornsgill and Mosedale (Figure 4.6) reveal a sequence of deposits associated with three glacial events of pre-Devensian, Devensian and Loch Lomond Stadial age and referred to as the Thornsgill, Threlkeld and Wolf Crags formations respectively (Table 4.3). The relationship between the tills of these three formations is shown in Figure 4.7. The primary interest in the site has been the unique sequence of glacial deposits and evidence for severe weathering of the lower, Thornsgill Till, forming what has been referred to as the Troutbeck Palaeosol (Boardman, 1985c). In recent years interest has turned to the sequence of fluvial terrace deposits in Mosedale; which

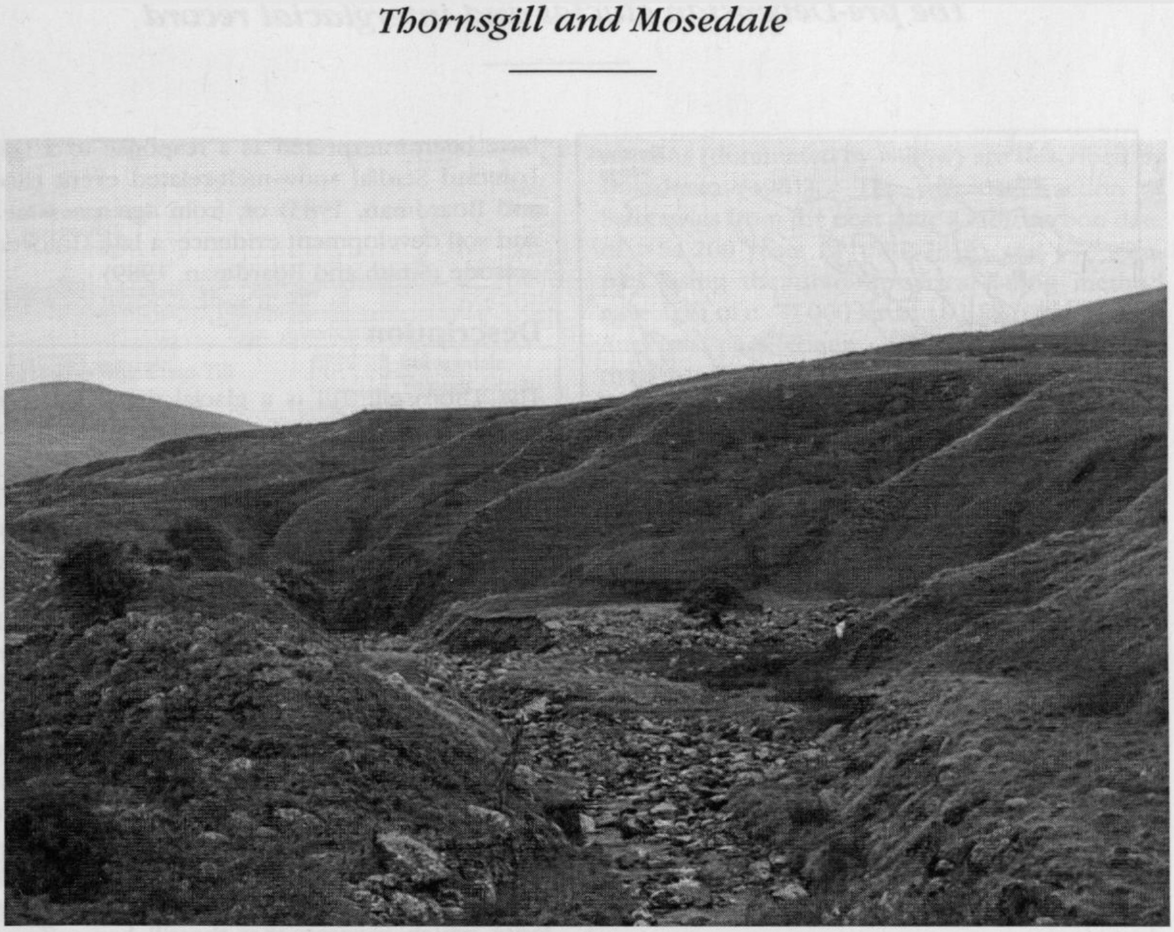

Figure 4.4 Incision of Mosedale Beck into Quaternary deposits, showing Late-glacial and Holocene river terraces and landsliding. (Photos: J. Boardman.)

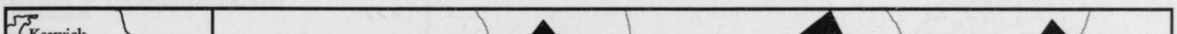

Figure 4.5 Direction of ice movement in the north-eastern Lake District (after Boardman, 1991).

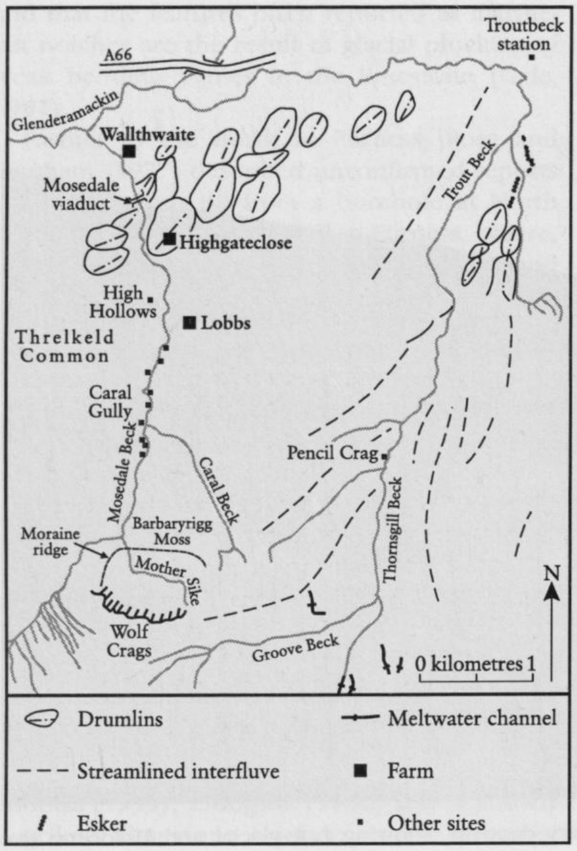

Figure 4.6 The valleys of Mosedale, Thornsgill Beck and Wolf Crags, showing exposed sites (after Boardman, 1985a).

have been interpreted as a response to a Loch Lomond Stadial snow-melt-related event (Rose and Boardman, 1983) or, from age assessment and soil development evidence, a late Holocene episode (Smith and Boardman, 1989).

Description

The Thornsgill Till is a glacial diamicton containing erratics from the west. At all sites it is severely weathered so that its original texture, clast composition and colour is difficult to establish. At Caral Gully (Figure 4.6) the till is 14 m thick and severe weathering occurs throughout its depth. At some sites the degree of weathering diminishes toward the base where relatively unweathered till is exposed, whereas at others the upper horizons of the weathered profile have been removed by subsequent glacial erosion and incorporated into overlying till as sheared blocks and weathered clasts. On the east side of Mosedale Beck (Figure 4.6) about 3 m of till overlies bedrock. The weathered zone here shows a downward decrease in intensity and textural variability, together with clast angularity, which suggests that the till has suffered frost shattering and reworking under periglacial conditions. In the weathered portion the matrix appears largely to be a response to in-situ chemical breakdown of mudstone, volcanic and

Table 4.3 Formal stratigraphy for the Quaternary of the north-eastern Lake District (after Boardman, 1985a).

Stage	Sediments and soil properties	Lithostratigraphy		Soil stratigraphy	Environment
		Formation	Member		
Flandrian	Colluvium, alluvium, landslip debris, etc.	Not investigated			
	Rubification, silt and clay translocation, gleying			Laddray Wood Palaeosol	Humid, warm, temperate
Devensian	Scree	Millbeck	Dodd Wood Scree Latrigg Grèzes Litées (stratified scree)		Periglacial
	Gravel Till	Wolf Crags	Wolf Crags Gravel Wolf Crags Till		Glacial/ glaciofluvial
	Till Sand, gravel and laminated beds Gravel	Threlkeld	Threlkeld Till Lobbs Sand and Gravel Mosedale Gravel		Glacial/ glaciofluvial
Ipswichian and earlier	Clast decomposition, rubification, solution, oxidation, clay flowage, clay translocation, gleying			Troutbeck Palaeosol	Humid, warm, temperate
Unknown	Till, sand and gravel	Thornsgill	Thornsgill Till, including sand and gravel bed		Glacial/ glaciofluvial

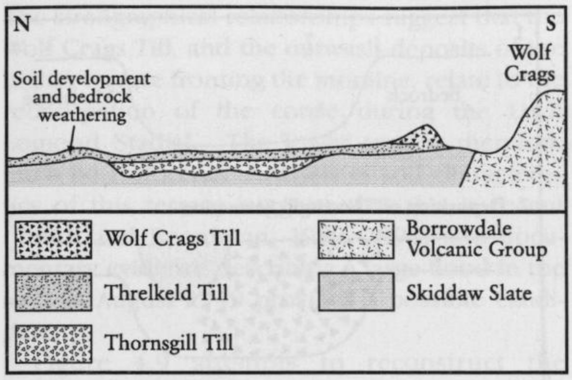

Figure 4.7 Relationship of the till units along Mosedale Beck (after Boardman, 1991).

granitic clasts, with many of the volcanic clasts heavily pitted and bleached. The weathering profile in the till is identified as the Troutbeck Palaeosol (Boardman, 1985c) (Figure 4.8).

In Mosedale Beck (Figure 4.6), a thin compressed peat bed overlies the Thornsgill Till and is itself overlain by reworked till and terrace gravels. Plant pollen and macroscopic plant remains (dominated by willow) are described by Boardman (1981). The cellulose fraction of Salix twigs from the peat gave a radiocarbon date of >54 200 years BP (SRR-2316) and two samples using the uranium-series dating method gave ages of *c.* 77 000 ka and 91 ka (Gordon and Andrews, pers. comm.). The peat bed is tentatively ascribed to an early Devensian interstadial or the end of the last (Ipswichian) interglacial.

The Threlkeld Till is found over most of the north-eastern Lake District. It generally forms the ground surface and on low ground drumlins are the characteristic landform (Figure 4.6). Its geographical distribution and relationship to other deposits and landforms implies that it is the till of the last major regional glaciation (Late Devensian). Its character varies with bedrock but in the Mosedale area it contains erratics from the central Lake District and from the Threlkeld microgranite outcrop, 3 km to the west. The Threlkeld Till stratigraphically overlies the Thornsgill Till but between the two, and overlying the weathered palaeosol, are sequences of unweathered gravel, of probable proglacial origin. The junction between the palaeosol and the

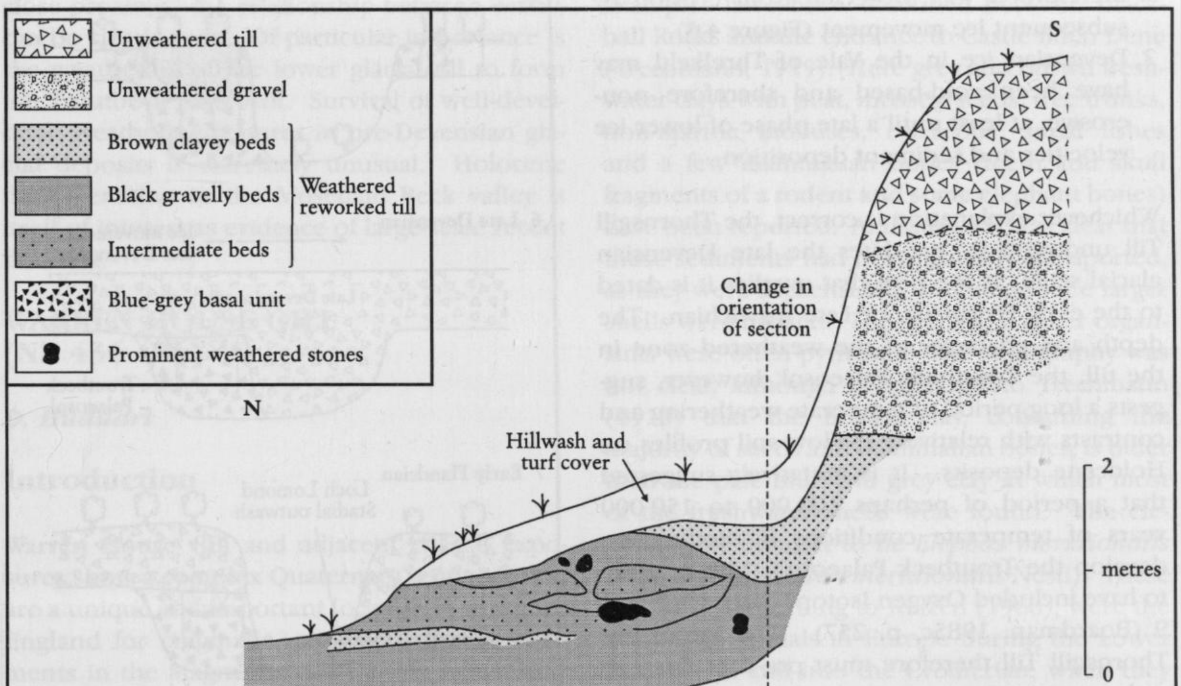

Figure 4.8 Stratigraphy in Mosedale (after Boardman, 1985c).

gravels is erosional, and at a higher level, blocks and clasts from the palaeosol are incorporated into the Threlkeld Till.

The Wolf Crags Till underlies the moraine ridge fronting Wolf Crags corrie. The till is a bouldery diamicton, oxidized in its upper part. Beyond the moraine, in the main Mosedale Beck valley, are two gravel terraces; the upper of which, 4 m above present stream level, grades into the moraine. The lower comprises large boulder bars, truncated soils and abandoned channels, indicative of a large recent event (Carling, 1997).

Interpretation

The development of a weathering profile, the severity of which diminishes towards the base, demonstrates that the Thornsgill Till was weathered *in situ*. The presence of friable clasts also argues against transport of weathered material to the site. Two possible explanations have been put forward for its survival.

1. Parts of the outcrop lie within a buried bedrock valley that runs at right angles to the direction of Devensian ice movement, and therefore it was protected from erosion by subsequent ice movement (Figure 4.5).
2. Devensian ice in the Vale of Threlkeld may have been cold-based and therefore non-erosive, at least until a late phase of lower ice velocities and sediment deposition.

Whichever explanation is correct, the Thornsgill Till undoubtedly pre-dates the late Devensian glacial stage, as the peat that overlies it is dated to the early Devensian or Late Ipswichian. The depth and character of the weathered zone in the till, the Troutbeck Palaeosol, however, suggests a long period of temperate weathering and contrasts with relatively shallow soil profiles on Holocene deposits. It is tentatively suggested that a period of perhaps 100 000 to 150 000 years of temperate conditions is required to develop the Troutbeck Palaeosol. This is likely to have included Oxygen Isotope Stages 5, 7 and 9 (Boardman, 1985c, p. 257). The age of the Thornsgill Till therefore must pre-date this age assignment.

There is little doubt about the age of the Threlkeld Till as this is regionally well known and equivalent to other locally named units associated with the late Devensian ice sheet.

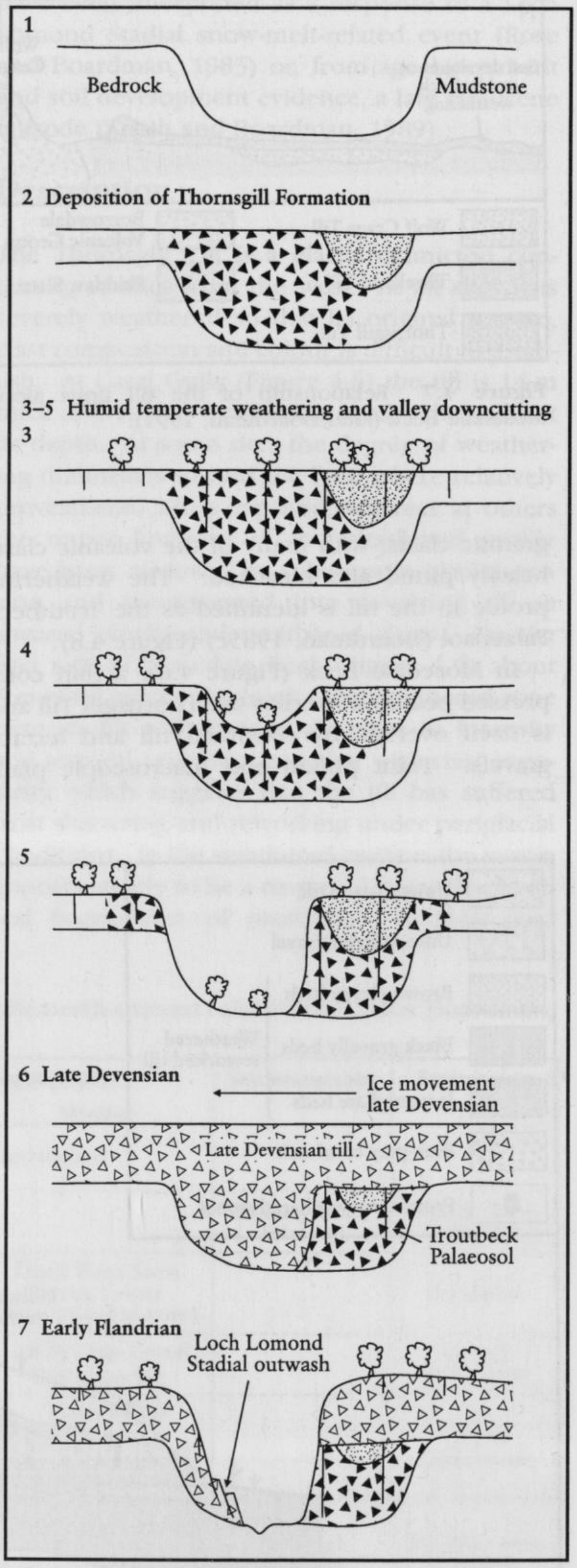

Figure 4.9 Quaternary landscape evolution in the Mosedale area: a reconstruction (after Boardman, 1985a).

The stratigraphical relationships suggest that the Wolf Crags Till, and the outwash deposits of the higher terrace fronting the moraine, relate to the reoccupation of the corrie during the Loch Lomond Stadial. The lower terrace therefore must be Holocene. Analysis of soil characteristics of this terrace suggests that this is recent (Smith and Boardman, 1989, 1994) and documentary evidence describing a large flood in the area in August 1749 provides a possible candidate.

Figure 4.9 attempts to reconstruct the Quaternary evolution of the landscape in the Thornsgill–Mosedale area. A bedrock valley is filled by pre-Devensian glacial deposits, which are then weathered and incised over a long period or periods of temperate conditions. Late Devensian glacial deposits then bury the landscape. During Late-glacial and Holocene times river incision occured to create the present topography.

Conclusions

Glacial deposits in the Thornsgill–Mosedale area constitute a unique British record of three glacial events. Because the deposits occur in close proximity the relationship between events can be clearly seen. Of particular importance is the weathering of the lower glacial till to form the Troutbeck Palaeosol. Survival of well-developed weathering features in pre-Devensian glacial deposits is extremely unusual. Holocene fluvial erosion in the Mosedale Beck valley is itself of interest as evidence of large-scale recent flooding.

WARREN HOUSE GILL (NZ 436 426)

D. Huddart

Introduction

Warren House Gill and adjacent coastal exposures show a complex Quaternary sequence and are a unique and important location in northern England for enigmatic, pre-glacial fissure sediments in the Magnesian Limestone, which may give information about the development of vegetation and climate back into the Tertiary, or at least the Pliocene–Early Pleistocene (Trechmann, 1919; Reid, 1920; West, 1968; Pennington, 1969a). It also has provided an important exposure of pre-Devensian till with Scandinavian erratics (Francis, 1970), loess (Trechmann, 1919) and a complex Devensian glacial sequence of sands, gravels, laminated clays and tills (Smith and Francis, 1967). The pre-Devensian sediments are no longer exposed as a result of tipping on the foreshore from Horden Colliery.

Description

Warren House Gill, in Durham, is situated about 2 km south-east of Easington Colliery and is an incised post-glacial valley in Magnesian Limestone cliffs that forms the back of a bay approximately 4 km long. The features of interest in the site extend further than the current site boundaries and a summary diagram of the relationships between the Quaternary deposits is shown in Figure 4.10.

Fissure deposits

Fissures that contain a variety of sediments, including freshwater clays with plant remains, are found in the Magnesian Limestone along a 10 km length of coast (Figure 4.11) and five examples have been described between Blackhall Rocks and the entrance to Castle Eden Dene (Trechmann, 1919). Here grey and brown freshwater clays with peat, mosses, seeds, tree trunks, non-marine molluscs, ostracods, small fishes and a few mammalian bones (teeth and skull fragments of a rodent and some elephant bones) have been reported. At fissure 5 it was clear that these sediments had been glacially transported, as they were slickensided, faulted and the larger shells were broken. The seeds and other organisms were often pyritized. The stratigraphy was not clear, although it appeared to Trechmann (1919) that the brown clay, containing the majority of seeds and mammalian bones, is older than the pale blue and grey clay in which most of the freshwater shells were found. The elephant was thought to be *Elephas meridionalis* (now *Archidiskodon meridionalis* Nesti). These elephants, according to Kurtén (1968), were the dominant animals in Europe during the Lower Pleistocene and into the Cromerian, when they showed a tendency to specialize into steppe and forest forms in contrast to their former habitation of savannas, bush steppes and woodlands.

The plant remains (seeds) were analysed by Reid (1919, 1920), who identified 114 species of

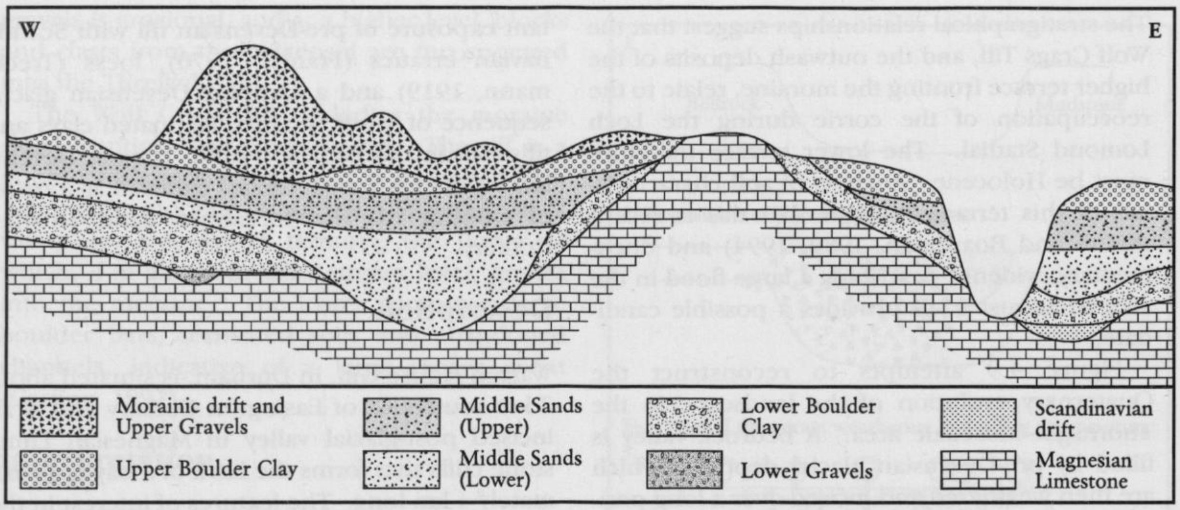

Figure 4.10 Summary diagram illustrating the relationships between the Quaternary deposits in eastern Durham (after Smith and Francis, 1967).

plant, including nine mosses; 89 species of flowering plant were generically determined and 58 to the nearest living species. Sixty-four per cent of the species were either no longer growing in Britain or were completely extinct. There was a large percentage of exotic, extinct species in this Castle Eden flora, as it was called, including a considerable element of Chinese and North American species. Mammalian bones were also found at the base of fissure 4 (Figure 4.11) and occurred among rubbly, calcreted Magnesian Limestone, which had small fragments of Scandinavian gravels. The fissure is overlain by loess-like sediment, and the bones of fallow and red deer or closely allied species are older, unworn and not glacially transported any distance. The younger blue clay contained 11 British temperate species and is clearly younger. The environment was aquatic, close to the sea and probably brackish (Reid, 1920).

Scandinavian Drift or the Warren House Till

At Limekiln Gill (4 miles north-west of Hartlepool) erratics were noted above the fissure, including pink and pale-grey gneiss, porphyries and a schist (Trechmann, 1915), which resemble the types found in the Scandinavian Drift at Warren House Gill. This term, 'Scandinavian Drift', had been used first by Howse (1864) to describe a clay bed that contained flints and pieces of *Cyprina islandica* at the mouth of the Tyne and overlying Magnesian Limestone at Trow Rocks near South Shields. He surmised that the flints might have come from Denmark. This was rejected both by Boswell (in a discussion of Trechmann's (1915) paper) and by Trechmann (1919) as flints are common in the Devensian sediments of east Durham, and Scandinavian rocks were often used as ship's ballast and have been found in the Tyne and along the coast. Nevertheless, larvikite was found near the mouth of Castle Eden Dene (Boulder Report, 1910–1911), to the north of Horden and on the shore opposite Warren House Gill (Trechmann, 1915). Porphyries and nordmarkite (a red, titaniferous syenite) were also reported on this coast. All these Scandinavian erratics resemble the types found in the Scandinavian Drift clay at Warren House Gill. The Scandinavian Drift is represented by a unit preserved in a SE-trending, pre-glacial depression in the Magnesian Limestone, near the centre of which occurs a fissure of uncertain depth but approximately 40 m wide. It is a dark, compact, tenacious, sandy clay, in places slickensided and up to 5 m thick, but this rapidly thins and disappears against Magnesian Limestone at the sides of the old valley. It is devoid of erratics from northern England or Scotland, except for locally derived Magnesian Limestone, red sandstone and marl, but does contain a characteristic Scandinavian suite, including gneiss, nordmarkite, larvikite, rhomb-porphyries, other porphyries of various types, quartzites and flint and

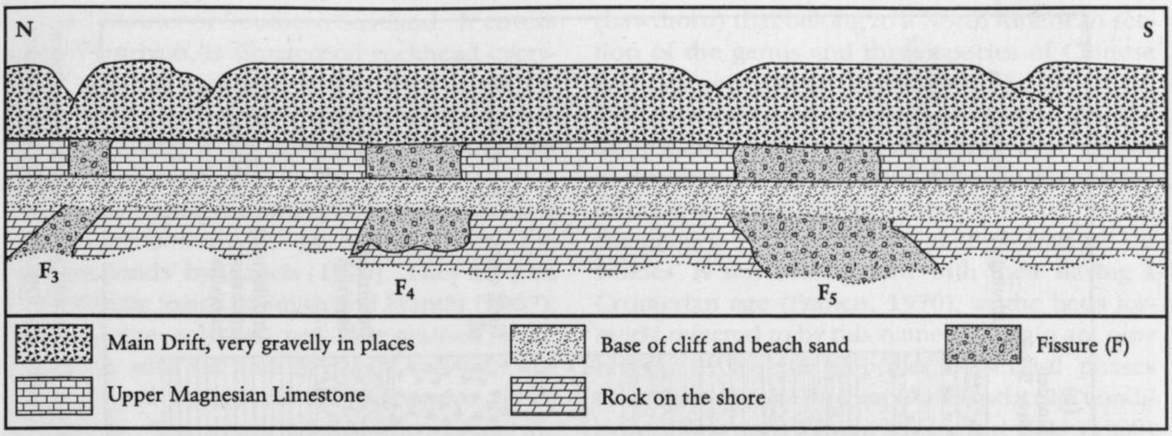

Figure 4.11 Fissure deposits on the Durham coast near Blackhall Colliery (from Trechmann, 1919).

chalk. Trechmann (1915) counted 500 clasts and 80% were igneous or metamorphic (along with a grey limestone) from the Oslo district of southern Norway and 6% chalk, flint and red–green Triassic material. The Scandinavian Drift was also shelly throughout, with many broken, arctic forms, now extinct in Britain (Trechmann, 1915, 1919), and abundant foraminifera have been obtained from a new exposure (Huddart, in prep.).

Loess

The upper section of the Scandinavian Drift consists of a bed of pale brown (fawn) sediment, between 0.3 and 4 m in thickness, full of rounded concretions and almost devoid of stones and stratification, although there are occasional layers of coarse sand. The unit breaks along vertical cracks and appeared to Trechmann (1919) to be loess banked up against the north-facing slope on the southern edge of the old valley. It passes upwards into a deposit of loess redeposited by water that has horizontal bedding, sand seams and fine gravel lines.

Devensian glaciogenic sequence

Stratigraphically above the Warren House Till but below the later Devensian till are a series of gravel deposits found in depressions in the Magnesian Limestone. Usually they are under 2 m thick but at Limekiln Gill they are 4 m thick, composed of cross-stratified sand and calcreted gravel, and extend over 30 m. North of Horden Point they are over 10 m thick and both examples contain unabraded shell fragments. The erratic suite is similar to the overlying till and there are no categorical Scandinavian rocks but mainly Lake District and Scottish erratics, with large percentages of gneisses, schists, Cheviot red and purple andesites, Lake District volcanics, dolerites, quartzites, Carboniferous Limestone, flint and Magnesian Limestone.

The Magnesian Limestone to the north and south of Warren House Gill is overlain by a tripartite Devensian glaciogenic sequence consisting of sands and gravels interbedded between two tills, called the Upper and Lower Boulder Clays by Smith and Francis (1967; Figure 4.12a). This succession is currently better exposed on the north side, where a grey-brown till, 2 m thick with red interbedded sediments, laminated and silty in places, lies above the Magnesian Limestone. This is overlain by 5 m of laminated, silty fine sand and clay units, which have had their original structure sheared into lenses by overriding ice. At Horden Point to the north of the gill an extensive glaciogenic sequence overlies 1.8 m of cavernous Magnesian Limestone and is illustrated in Figure 4.12b. Above this coastal stratigraphical succession at the western end of Warren House Gill, at the newly constructed Horden Sewerage Works, a complex glaciogenic sequence higher in the succession was exposed and is illustrated in Figure 4.12c. The Lower Boulder Clay, or Blackhall Till (Francis, 1970) attains a maximum of 15 m over this coastal plain and is the lowest stratigraphical unit formed during the Devensian ice advance and is generally a highly compacted, stiff, darkgrey or grey-brown sandy till with erratics from

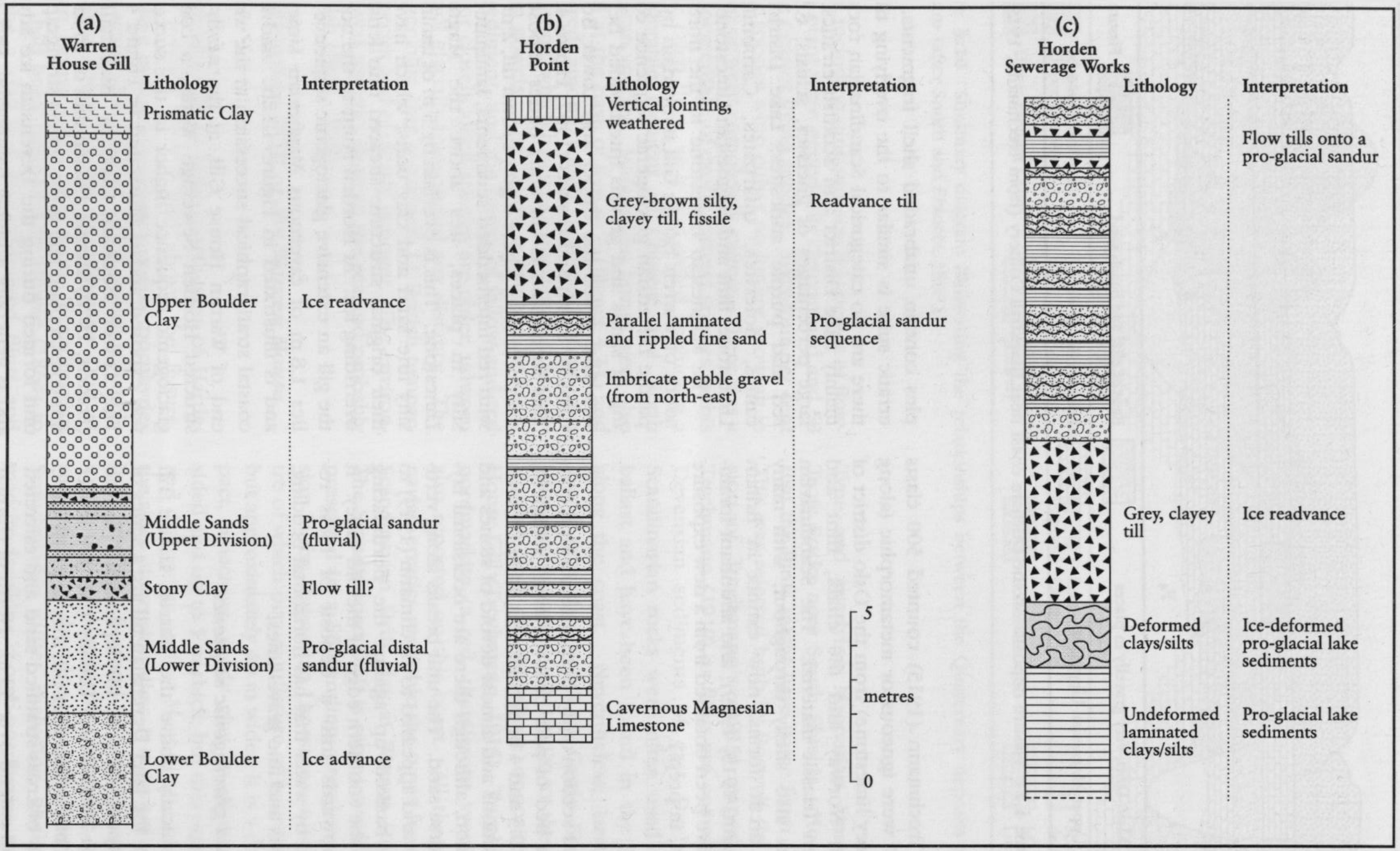

Figure 4.12 Devensian glaciogenic sequences and their interpretation: Warren House Gill and Horden. (a) Tripartite Devensian glaciogenic sequences, Warren House Gill (after Smith and Francis, 1967). (b) Devensian glaciogenic sequence, Horden Point. (c) Devensian glaciogenic sequence, Horden Sewerage Works.

the Lake District or Southern Scotland. It covers most of Durham, is situated on rockhead everywhere and this rockhead is disturbed in places. Striae, till fabrics and the erratic distribution suggest ice moving from north-west to south-east across the county.

Along the eastern coastal plain the lower till is overlain predominantly by sands, called the 'Peterlee Sands' by Francis (1970). They are part of the Middle Sands of Smith and Francis (1967), who describe a lower, red, fine-grained sand, commonly with silt and clay beds and sporadic units of sand and gravel and an upper gravel with sands. The upper till has been called the 'Horden Till' by Francis (1970), from the type locality on the north side of Warren House Gill, and along this coast reaches a maximum thickness of about 14 m and where unweathered is a dark-brown to purplish brown, stiff clay with a similar texture to the lower till. It has a sharp base at some localities and at others the contact is gradational.

The so-called 'Prismatic Clay' generally consists of a dull brown, silty and sandy clay with scattered erratics and many pronounced columnar joints in its upper part, grading to blocky below, but in many locations has much of the characteristics of till and grades into the underlying deposit. It is weakly layered in some exposures and as Coupland and Woolacott (1926) noted it maintains a roughly constant thickness for considerable distances, even down valley sides and on to bedrock. It is widespread in eastern Durham and most common on the upper till.

Interpretation

Fissure deposits

Reid (1920) thought that the lower fissure deposits must be older than the Cromerian, by comparison with the European Middle Pleistocene to Pliocene sequences. The environment was thought to be one of a rocky or pebbly bedded river as there was the presence of species such as *Cotoneaster*, *Potentilla argentea* and *Oxalis corniculata*, which suggest an upland river and a rocky valley in limestone with pastures. Woodlands were indicated by some of the following: *Liquidambar* (sweet gum), *Carpinus laxiflora* (Japanese hornbeam), *Betula alba* (white birch), *Alnus viridis* and *A. glutinosa* (alder species), three species of *Crataegus* (hawthorn) that belong to a North American section of the genus and three species of Chinese and Japanese *Rubus* (blackberry). Lesne (1920, 1926) identified nine species of insects from the same material and found that three were extinct in western Europe and four were closely related to present forms. Lesne's suggestion that two of the genera 'recherchent les stations fraiches ou froides' is not inconsistent with their having a Cromerian age (Francis, 1970), as the beds formerly referred to by this name in Britain are now known to include deposits of several phases encompassing both temperate and cold conditions (West and Wilson, 1966), but Reid (1920) suggested that they confirmed the Pliocene age. Pennington (1969a) considered that, although the Castle Eden flora was of doubted age, it might be compared with the Upper Pliocene floras of Poland (Szafer, 1946), or to an earlier stage. Boulter (1971b) has suggested that there could be links between the Castle Eden flora from the lower clay and those floras of Miocene to Early Pliocene age in Derbyshire, but West (1968) preferred an early Pleistocene age. The non-marine molluscs have been reported by Kennard and Woodward (1919, p. 200), but although they indicate a fluvial habitat the faunal assemblage is undiagnostic as to age.

Reid (1920) considered the younger fissure fills to be possibly Cromerian and this is likely. There was considerable disturbance of the rock adjacent to and enclosing the fissures and in every case there was erosion across their surfaces. The fissure fills were thought not to be the result of 'collapse breccias' by Trechmann (1915) but were the result of glacial processes. He suggested that the fissures lay open before the Scandinavian ice reached the area and that they were filled with sediment carried by that ice. He considered that rock fragments in the fissures were slickensided by movement during compaction of the breccia under the weight of the overlying ice. However, it seems much more likely that the fissures were first formed during and after the solution of the sulphates following the post-Permian uplift and that most of the material from the beds now eroded away fell in at about this time. Subsequent compaction of the resultant breccias provided space for the gradual accumulation of material towards the fissure top and it is suggested that such compaction gave rise to surface depressions into which Pleistocene sediment was deposited ahead of, or under, the Scandinavian ice.

Scandinavian Drift or the Warren House Till

Trechmann (1915) correlated the fauna in the Scandinavian Drift with the fauna from the Bridlington Crag in Holderness. The Scandinavian Drift, or Warren House Till, indicates a major cold period sufficiently long and intense for a large ice cap to have formed over Scandinavia and extending as far as the East Durham coast. Trechmann preferred an origin by Scandinavian land-based ice approaching the Durham coast rather than ice-rafted glaciomarine sedimentation, especially as Swedish quartz-porphyries and rapakivi-granite have been found on the southern Yorkshire coast but not on the Durham coast. Such an ordered distribution could not be explained by icebergs floating randomly across the North Sea and hence he concluded that this must have been a terrestrial ice sheet. However, Beaumont (1968) argued that this till was deposited from a floating ice shelf that did not come into contact with any bedrock until it grounded close to the Durham coast. During this grounding stage it incorporated the arctic marine fauna. This helped explain how the Scandinavian ice could reach the British coast before local ice from western Britain could arrive. Hence there is no need to postulate that the Scandinavian ice sheet expanded more rapidly, for once the ice sheet became buoyant its thickness would be greatly reduced and its speed of advance as an ice shelf would be increased by a factor of five to ten times compared to its terrestrially based speed. At the height of the glaciation the sea level in the North Sea would fall and therefore the floating ice shelf would have become grounded at progressively greater distances from the Durham coast. Therefore the invasion of the Durham coast took place during the very early stages of the glacial phase and it was the first ice to reach the coastal area. The Warren House Till has been correlated with the Basement Till of Holderness and has been thought to be Wolstonian in age (Smith, D.B. *et al.*, 1973; Lunn, 1995; Hughes *et al.*, 1998). However, West (1963) and Smith and Francis (1967) attributed it to the Anglian.

Loess

The overlying loess is gradational with the Warren House Till and there are contortions in both, and therefore ice must have overidden this sediment, although the main mass of loess is banked up against the valley after the Scandinavian ice sheet had begun to retreat. This loess probably indicates a cold periglacial zone with outblowing winds from the end of the Wolstonian glacial (Shotton, 1981) and not as Trechmann (1919) thought from an interglacial. Smith and Francis (1967) placed it in the Hoxnian interglacial. However, this loess and loess in soils developed over the Magnesian Limestone outcrops could have been emplaced in an extraglacial, early Late Devensian environment according to Catt *et al.* (1974). Thus again there is dispute as to the time period of deposition for this loess.

Devensian glaciogenic sequence

There seems to be two possible origins for the gravels in depressions in the Magnesian Limestone: they might be associated with subglacial (Trechmann, 1915), or pro-glacial (Smith, 1981) glaciofluvial transport, but related to ice advance probably during the Devensian.

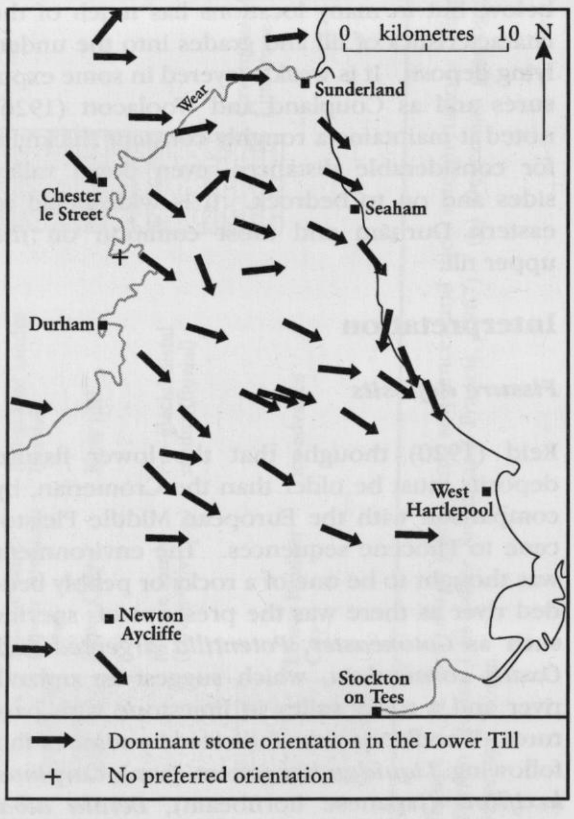

Figure 4.13 Stone orientation directions from the Lower Till, eastern Durham (after Beaumont, 1971).

Evidence for a period of deglaciation between the upper and lower till sheets is meagre and is confined to two possible weathering horizons developed on the surface of the lower till. In the inland valleys the ice melt between the upper and lower tills led to the deposition of thick glacio-aqueous sediments called the 'Durham Complex' by Francis (1970). During deglaciation, water in both subglacial and supraglacial environments led to a variety of sediments and landforms. The laminated silty clays shown in Figure 4.12c indicate pro-glacial glacio-lacustrine sedimentation, but whether it was in this phase, or associated with a later readvance is debatable. The lower sands have been interpreted as outwash from the ice that deposited the underlying till and the upper gravels and sands from ice that deposited the upper till. The extent of the Horden Till (Upper Till) shown in Figure 4.14 implies that during deglaciation the margin of the ice lay along the present coastal zone and it is probable that considerable quantities of meltwater were liberated and that laminated clays were deposited in lakes (possibly the laminated clays at Horden Sewage Works), and that a number of glacial drainage channels survive from this period. The till-fabric pattern suggests movement of ice down the present-day coast and impinging on to the Tees lowlands (Figure 4.13). This unit has fewer – but more far-travelled erratics – than the lower till. There are disturbances reported in the underlying sediments below the Horden Till, as in Figure 4.12c and at Sheraton, where in a road cutting a large thrust fault was visible in laminated clays, which did not pass up into the overlying till. These situations indicate disturbance of the laminated clays caused by the ice advancing. There are glacial landforms associated with this upper till ice, such as the NNW-trending ridges forming moraines with an east-facing ice-contact slope between Easington and Elwick and the pro-glacial lake Edder Acres, which overflowed through channels, as at Kelloe (Figures 4.14 and 4.15). Laminated clays were deposited in this lake, as at Shotton brickpit, as advancing ice blocked existing drainage. Evans (1999) suggested that a lobe of Tweed–Cheviot ice, probably on a deforming bed, remained active along the north-east coast after ice from the west (Tyne

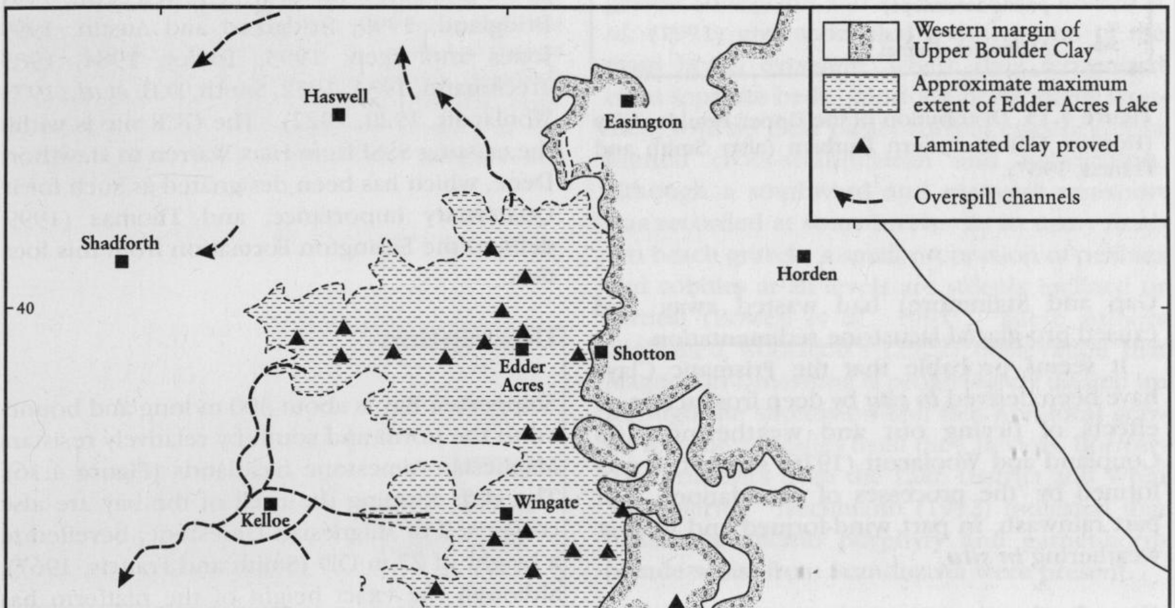

Figure 4.14 Lake Edder Acres, eastern Durham (after Smith and Francis, 1967).

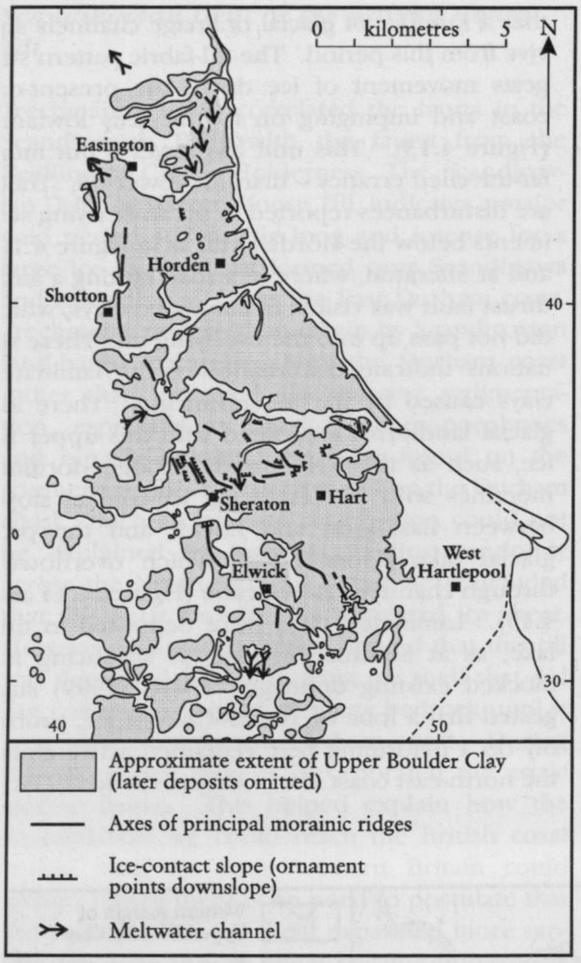

Figure 4.15 Distribution of the Upper Boulder Clay (Horden Till) in eastern Durham (after Smith and Francis, 1967).

Gap and Stainmore) had wasted away, and caused pro-glacial lacustrine sedimentation.

It seems probable that the Prismatic Clays have been derived *in situ* by deep frost action or effects of drying out and weathering. As Coupland and Woolacott (1926) suggest, it was formed by 'the processes of denudation ... in part rainwash, in part wind-formed and in part weathering *in situ*.'

Conclusions

The deposits reported by various authors from Warren House Gill and the surrounding Durham coast have revealed an extremely important Quaternary succession. Some of the fissure deposits go back at least to the Early Pleistocene, and the younger fissure deposits are probably Cromerian in age. Both the older and younger fissure deposits appear to be much older than most other Quaternary deposits in northern England, apart from the Derbyshire pocket deposits. The Devensian sequence at Warren House Gill and along the adjacent coast is typical of much of County Durham and illustrates the variety of deposits and environments laid down during the advance, retreat and readvance of a complex ice sheet.

SHIPPERSEA BAY (NZ 443 453)

D. Huddart

Introduction

Shippersea Bay, Easington in Durham, is of great importance for its potential in unravelling the Late Quaternary stratigraphy of north-east England and for reconstructing former sea levels. It is the site of the Easington raised beach, which is interglacial but there has been much discussion as to which interglacial age it relates to and hence much debate about the chronology of the associated glacial succession, both above and below the beach (Bowen *et al*., 1991; Bridgland, 1999; Bridgland and Austin, 1999; Jones and Keen, 1993; Tooley, 1984, 1985; Trechmann, 1931, 1952; Smith, D.B. *et al*., 1973; Woolacott, 1920, 1922). The GCR site is within the existing SSSI from Hart Warren to Hawthorn Dene, which has been designated as such for its Quaternary importance, and Thomas (1999) defined the Easington Formation from this location.

Description

Shippersea Bay is about 300 m long and bounded to the north and south by relatively resistant Magnesian Limestone headlands (Figure 4.16). The cliffs forming the back of the bay are also composed of Magnesian Limestone, bevelled to a height of 27 m OD (Smith and Francis, 1967), although the exact height of the platform has been suggested as anywhere between 18 and 32 m OD (Figure 4.17). This rock platform is capped by 4 m of sand and gravel regarded by Woolacott (1922) and Trechmann (1931) as the Easington raised beach. It is composed of sand and gravel, some beds of which are calcreted. The lowest metre of beach consists of poorly

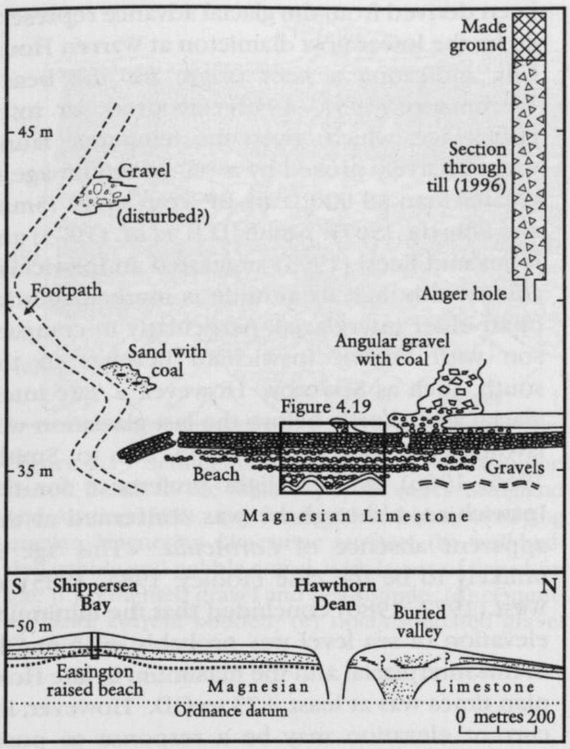

Figure 4.16 Sections in the cliffs north of Easington. The upper part shows Shippersea Bay exposures since 1996, examined by Bridgland and Austin (1999). The location of Figure 4.19 is noted. Below shows the sections based on observations and records of former exposures described by Smith and Francis (1967). Their Middle Sands and Gravels (stippled) separate Lower and Upper Boulder Clays (no ornamentation). The stratigraphical location of the Easington raised beach is noted (after Bridgland and Austin, 1999).

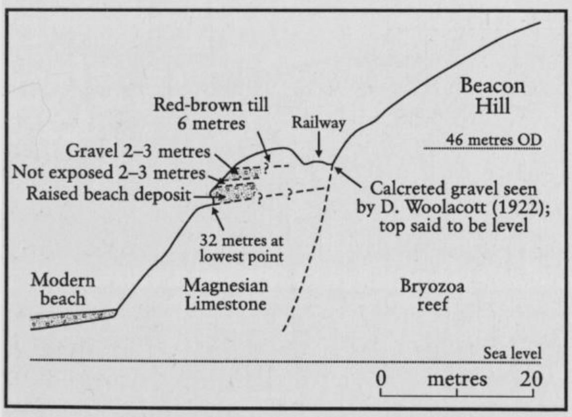

Figure 4.17 Diagrammatic section of the Easington raised beach and associated deposits (after Woolacott, 1922; Bowen *et al*., 1991).

cemented coarse sand and fine gravel that pass into coarser gravels, which are highly cemented in the uppermost 2.5 m. This was reported by Woolacott (1922) to be overlain by soft sand containing shell fragments. Shells and shell fragments are abundant in the lower parts of this succession but seem to be less abundant in the calcreted beds. The lateral extent of the raised beach is in doubt and it is not always easy to differentiate from glacial gravels, but Smith and Francis (1967) suggest that it is post-dates the Lower Boulder Clay and pre-dates the Upper Boulder Clay.

The shells within the gravels (Woolacott, 1920, 1922; Bowen *et al*., 1991) indicate a temperate marine origin (Table 4.4). Some of the gravels are bored by marine molluscs and annelid worms (Woolacott, 1920, 1922; Trechmann, 1931). In addition the land snail (*Helix* species) has been recorded and Woolacott recorded several species of foraminifera and ostracods. Woolacott (1920) noted that many rodent's bones had been found a little further to the south in the gravel. The gravels are bedded (Figures 4.18 and 4.19), with a clean sandy matrix and they lack the variably shaped, often angular, gravel that is characteristic of the glacial gravels (Bridgland and Austin, 1999). Bowen *et al*. (1991) give a detailed a description of the main beach exposure, where they recognized eight separate beds. Most are horizontally stratified, with no clear palaeocurrent evidence from limited cross-stratification and imbrication, although a southward and eastward transport was recorded at some levels. As in many modern beach gravels, a small proportion of pebbles and cobbles at all levels are steeply inclined or vertical (Bowen *et al*., 1991). These authors confirmed Woolacott's (1922) observation that Magnesian Limestone is progressively diluted up through the succession and that non-local gravels include andesites from the Cheviots, Borrowdale Volcanics from the Lake District and Whin Sill dolerite. Trechmann (1952) indicated that halleflinta, rhomb porphyry and garnet-hornblende schist from Scandinavia were present.

Interpretation

Woolacott's original interpretation of the gravels as a raised beach has generally been accepted, but his view that it was a Late-glacial or a post-glacial beach was disputed by Lamplugh (quoted by Woolacott (1922) and Trechmann (1931,

Table 4.4 Shell list from the Easington raised beach (based on Woolacott, 1920, 1922).

Species	
Littorina littorea	common
Littorina obtusata	common
Littorina rudis	
Patella vulgata	common
Nucella lapillus	
Cliona sp.	
Polydora sp.	
Saxicava sp.	
Buccinum undatum	
Arctica islandica	
Mytilus edulis	
Pecten sp.	
Rhynchonella psittacea	
Helix sp.	

1952)). The presence of exotic clasts in the raised beach indicates that at least one major glacial had affected the area prior to the formation of the beach, and it is overlain by a glacial succession. The Scandinavian rocks must have been derived from the glacial advance represented by the lowermost diamicton at Warren House Gill, indicating a later origin for the beach. Trechmann (1931, 1952) favoured an interglacial age, which, given the temperate fauna, was effectively proved by a ^{14}C minimum age of greater than 38 000 years BP from shells (Smith and Francis, 1967). Smith, D.B. *et al*. (1973) and Jones and Keen (1993) suggested an Ipswichian affinity, although its altitude is more suggestive of an older interglacial, particularly in comparison with known Ipswichian beaches to the south, such as Sewerby. However, a 'late interglacial age' shortly before the last glaciation was favoured by Baden-Powell (in litt. to Smith, 1965, 1966), with a slight preference for the Ipswichian, although he was concerned at the apparent absence of *Corbicula*. This age is unlikely to be the case (Tooley, 1984, 1985) as West (1972, 1980) concluded that the minimum elevation of sea level was probably +7.5 m OD in this interglacial and the maximum in late Hoxnian times was at least +23 m OD. However, its current elevation may be a response to post-Ipswichian tectonic movement (Shotton, 1981), although there is no real evidence for this.

Figure 4.18 Easington raised beach, April 2000. (Photo: D. Huddart.)

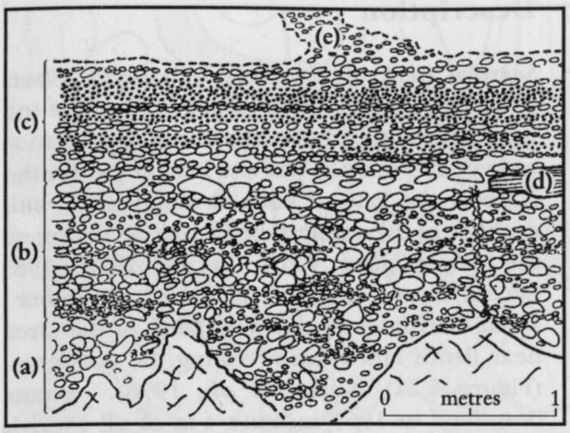

Figure 4.19 Sedimentological detail of the Easington Raised Beach in the main exposure (after Bridgland and Austin, 1999). (a) Sand with cobbles, overlying uneven Magnesian Limestone surface; (b) well-bedded cobble and pebble gravel, with layers of fine shingle; (c) cemented gravel and pea-shingle; (d) cemented sand, current bedded; (e) unconsolidated gravel and shingle.

Bowen *et al.*(1991) and Thomas (1999) correlated the beach with Oxygen Isotope Stage 7, with a reworked fauna from Oxygen Isotope Stage 9, and both Lunn (1995) and Hughes *et al.* (1998) suggested that the beach is Ilfordian in age, about 200 000 years old. This was based on the amino acid analyses of the shells, which had suggested that the beach be correlated with Oxygen Isotope Stage 7 (Bowen *et al.*, 1991), although two shell populations were identified amongst the analyses of *Patella vulgata*. An older one with a mean amino acid D/L ratio of 0.228 ± 0.12 ($n = 5$) and a younger population, with a ratio of 0.174 ± 0.01 ($n = 5$). The older population is interpreted as being reworked from deposits dating to a previous higher sea level, which Bowen *et al.* (1991) attributed to Oxygen Isotope Stage 9. They regarded the younger population as indigenous to the Easington raised beach and correlated with Oxygen Isotope Stage 7.

No comparable raised beach deposits have been found in north-east England, but there is a widespread gently sloping platform cut into the Magnesian Limestone in coastal districts to the north, at least as far as South Shields. The extent of this platform, the landward edge of which abuts against an inferred exhumed cliffline at about +31 m OD, strongly suggests it is marine in origin and possibly correlated with the Easington raised beach (Bowen *et al.*, 1991; Smith, 1994).

The relationship between the Easington raised beach and the marine sediments at Speeton (Austin and Evans, 1999) and Kirmington (Bridgland and Thomas, 1999) is unknown. Wilson (1991) provided a useful synthesis for the argument for the age of the Speeton Shell Bed and concludes that it was deposited during Oxygen Isotope Stage 7. However, Bowen and Sykes (1991) argue against the validity of Wilson's amino acid ratio data owing to the fact that she used museum shell collections coated in resin. Nevertheless, the material analysed by Bowen and Sykes (1991) shows a standard deviation of 17% from the mean and the lowest amino acid ratio of 0.0154 hints at an Ipswichian date. This is the conclusion reached by Knudsen and Sjerup (1988) when they analysed the amino acid ratios of foraminifera from the Speeton Shell Bed.

At Kirmington most authors have suggested a Hoxnian age for the deposits (Watts, 1959; Boylan, 1966b; Catt and Penny, 1966; Smith, D.B. *et al.*, 1973), but Bridgland and Thomas (1999) suggest that the transgression that deposited the marine gravels corresponds to Oxygen Isotope Stage 11. According to evidence from mammalian biostratigraphy (Schreve, 1997) this is the true age of the type Hoxnian deposits. However, there seems no doubt that the raised beach deposits at Sewerby are Ipswichian. Thus it appears that the Easington beach may well be of an age between the Kirmington deposit and Sewerby and equivalent to the Speeton Shell Bed.

Overlying the raised beach are diamictons and gravels of glacial origin thought to be of Late Devensian age. These deposits are widespread as a capping to the cliffs in this area and are well represented within the infills of pre-glacial or subglacial valleys that intersect the coast. However, because the contacts between the beach and these deposits are obscured, there has been a serious problem in distinguishing the deposits of different glaciations within the infills of these valleys, some of which are likely to be of considerable age. Smith and Francis (1967) intimated that the beach gravels had been incorporated into the upper division of their glacial Middle Sands by reworking, a view that might raise questions about the whole basis for pre-Devensian glacial sediments of the Durham coast, were it not for the unlikelihood that such an extensive raft of interglacial sediment could have been transported and deposited horizontally, with no sign of disturbance (Bridgland and Austin, 1999). It is evident though that there are extensive gravels that lack shells cropping out at a similar level within the coastal exposures. These are part of the glacial sequence and the determination of their stratigraphical relationship with the raised beach becomes of considerable importance. It seems probable that they are younger and related to Late Devensian glaciofluvial sandur sedimentation during advances and retreats of the coastal ice.

Conclusions

Although there are some problems associated with the stratigraphy and dating of the Easington raised beach it seems probable that the beach is related to a high interglacial sea level in Oxygen Isotope Stage 7 and that it is *in situ*. It is likely to be older than the Warren House Till, which is believed to be as old as Oxygen Isotope Stage 6 (Francis, 1970; Thomas, 1999) and older than the East Durham and Wear Formations (Thomas, 1999), which are Late Devensian and glacial in origin.

SCANDAL BECK (NY 742 024)

W. Mitchell

Introduction

Exposures in the bank of Scandal Beck, a tributary of the River Eden, reveal a complex Quaternary stratigraphical succession. The succession has been described as either a series of interglacial organic lake muds with some of the peat having been incorporated into an overlying till (Carter *et al.*, 1978), or organic sediments that are included in a lower sandstone-rich till, overlain by a limestone-rich till, providing evidence for two glacial events (Letzer, 1978, 1981).

This is an important and unique site for northern England, as evidence of possible glacial events before the Late Devensian is rarely preserved in this region. The site is defined as the stratotype of the Scandal Beck Bed (Thomas, 1999). The bed is not related to any other formal lithostratigraphical unit but is thought to be related to organic sands at Low Hurst (Evans and Arthurton, 1973; Thomas, 1999) ascribed to an Ipswichian age (Oxygen Isotope Stage 5).

Description

Scandal Beck, in Cumbria, is a small tributary stream in the upper Eden valley near the interfluve area with the Rawthey drainage, at an altitude of 275 m OD. The site lies on the southern edge of the Vale of Eden drumlin field, with a number of these glacial bedforms occurring near the site (Figure 4.20) (Letzer, 1978, 1987). Recent fluvial erosion has led to a number of small landslides in the west bank of the stream near Brunt Hill Farm revealing the stratigraphy (Figure 4.21) (Carter *et al.*, 1978). Sections described in 1969 indicate 4 m of till overlying 2 m of fluvial sediments with organic lenses and with more notable peat layers towards the base (Carter *et al.*, 1978). Further work in 1972 involved augering the stream bed, when the sequence was extended a further 2 m in depth, revealing more beds of clay with interstratified peat and a base of dark clay, but no till. Samples for pollen analysis were taken on both occasions, although the published diagrams are ambiguous with respect to stratigraphical location (Carter *et al.*, 1978).

Field observations by Letzer in 1976 and in 1981 revealed a more complex stratigraphical succession (Figure 4.21). Observations noted the incorporation of clasts of peat into a till, the deformation of the organic sequence and the presence of two tills above the peat (Letzer, 1978). Subsequent investigations (Letzer, 1981) indicated the presence of a lower till probably extending below the peat (Figure 4.21b). A field excursion in 1988 re-examined the site and although exposure was poor, sheared organic material in the sand and clay sequence was observed overlain by two distinct tills (Rose and Mitchell, 1989). No evidence was seen of the lower till.

Attempts were made to obtain radiocarbon age estimates from samples of the lower exposed peat (Shotton *et al.*, 1970; Shotton and Williams, 1971). Two dates were obtained; the first, after alkali pre-treatment, gave a date of 36 300 + 2100/ –1700 years BP, whereas an infinite date of >25 000 years BP was obtained after humate extraction (Shotton *et al.*, 1970; Carter *et al.*, 1978). A further sample from a wood fragment in the upper organic layer give a date of >32 500 yrs BP (Shotton and Williams, 1971). Little confidence can be placed in these dates and the section clearly needs to be revisited and sampled for new material.

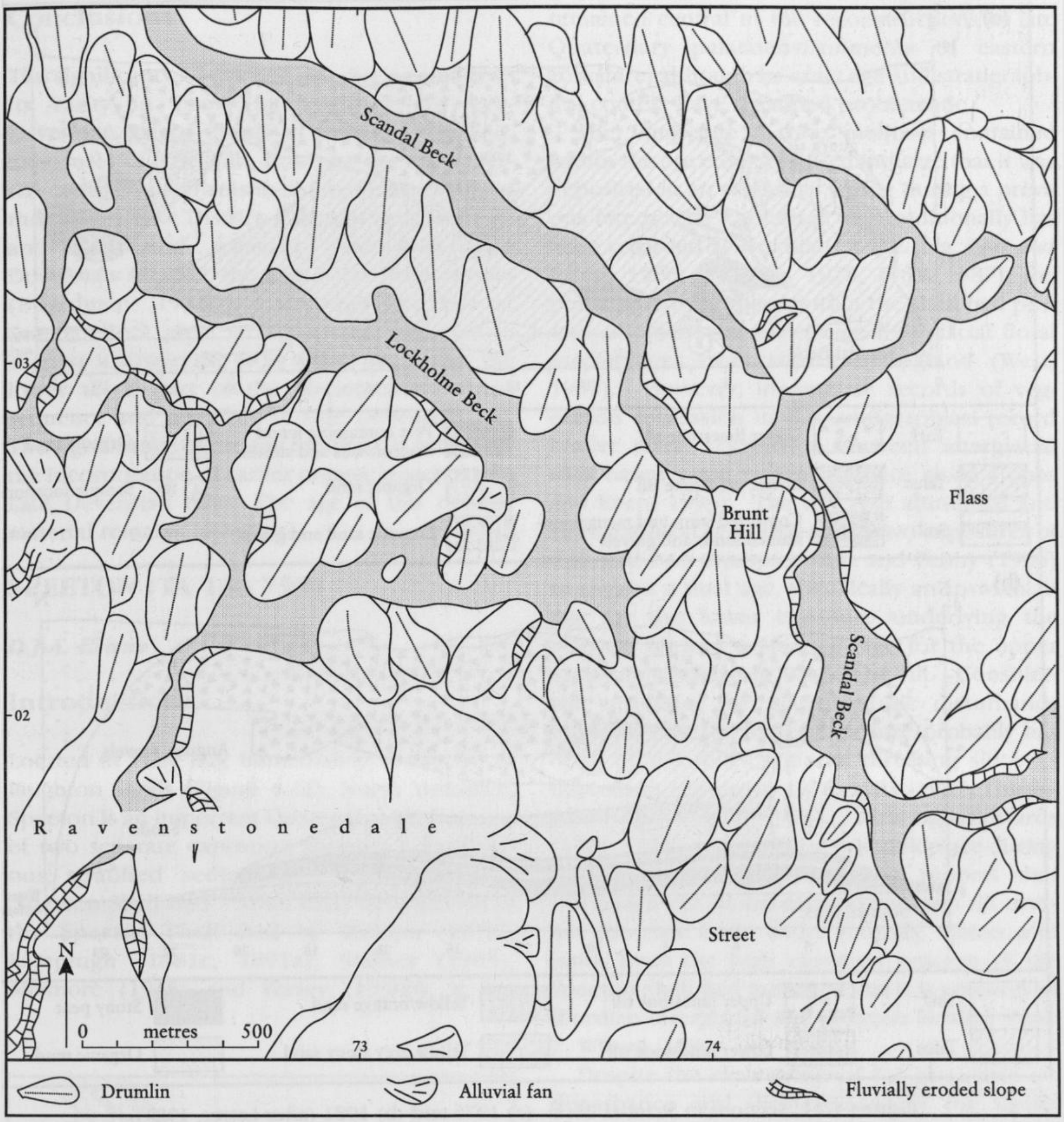

Figure 4.20 Geomorphological map of the area showing the position of the Scandal Beck site within the drumlin field. (After Letzer, 1978).

Interpretation

Pollen analysis of the exposed succession allowed the identification of three local pollen assemblage zones that are thought to be typical of the closing stages of an interglacial (Carter *et al.*, 1978). The lowermost zone contains high values of *Quercus* pollen with other thermophilous woodland species. The middle zone contains high percentages of *Alnus* and the presence of water plants such as *Nuphar* and *Nymphaea* indicates wetter conditions. The upper zone is dominated by *Pinus* and indicates a boreal, rather than temperate, climate thought to indicate climatic cooling (Carter *et al.*, 1978). The general pattern and the presence of *Carpinus* pollen with *Alnus* in pollen assemblage zone ScB-2, is thought to correlate Scandal Beck with Zone III of the Ipswichian interglacial

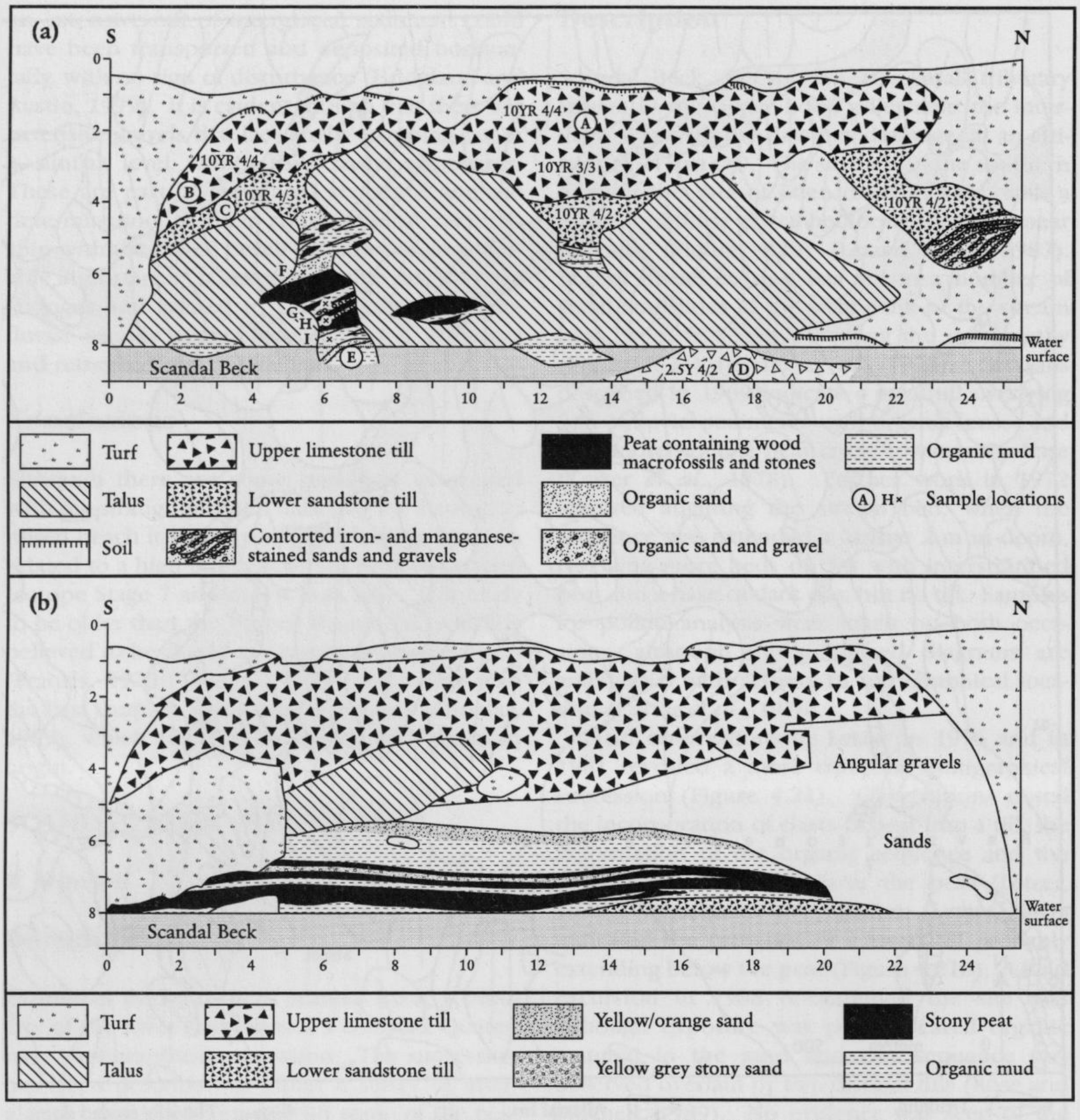

Figure 4.21 Sections in Scandal Beck: (a) 1976 and (b) 1981 (after Letzer, 1981).

(Carter *et al.*, 1978). A further series of samples taken from the stream-bed gave a similar pollen signal from sediments that were thought to underlie stratigraphically the riverbank exposures. This repetition of the pollen assemblages is interpreted as the result of glacial overthrusting of the sequence, although it may reflect an interglacial climatic sequence that was much more complex with a series of climatic oscillations (Carter *et al.*, 1978).

The basal grey till underlying the organic sediments in 1981 and interpreted by Letzer (1981) as the same lower grey till that was seen above the organic sediments in 1976 is explained by glaciotectonic thrusting of the sediments. This has led to a thickening of the sediment sequence and a repetition of the lithological units. This is confirmed by the repetition of the pollen biozones and suggests that glaciotectonic disturbance, rather than complex interglacial climatic fluctuations, is the preferred interpretation (Carter *et al.*, 1978).

Conclusions

The significance of this site was due originally to its rarity in providing evidence for pre-Devensian glacial events in northern England. Exposures of older tills, however, are controversial owing to problems in dating them. Thus, in the eastern Lake District, a deeply weathered till and associated palaeosol underlies Late Devensian till, but the age is far from certain (Boardman, 1985c). Although the site at Scandal Beck gives stratigraphical evidence to suggest a lower till, it is more likely that the lower till is part of the glaciotectonic thrust sequence and therefore of Late Devensian age. The significance of the site therefore is related to the incorporation of earlier organic material into Late Devensian tills. The age of this organic material remains uncertain.

SPEETON (TA 146 759)

D.J.A. Evans

Introduction

Located in Filey Bay, immediately south-east of Reighton Sands (Figure 4.22), North Yorkshire, Speeton is an important Quaternary site because of two separate exposures through a fossiliferous stratified sedimentary unit called the 'Speeton Shell Bed'. Since early descriptions of the Speeton Shell Bed by Phillips (1875), Lamplugh (1881c, 1891a), Stather (1905), Melmore (1935) and Versey (1938b), it has remained central to the reconstructions of late Quaternary palaeoenvironments of eastern Yorkshire, although its exact age and stratigraphical context have remained problematic.

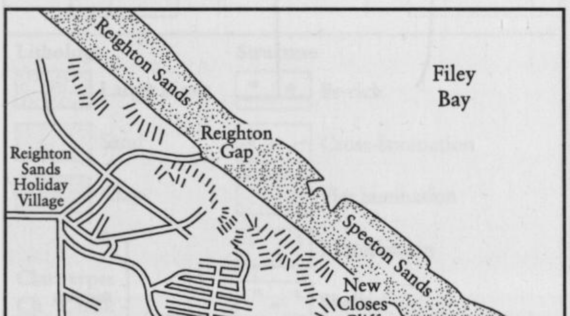

Figure 4.22 Map of the Speeton Shell Bed localities.

The temperate marine molluscs contained within the Speeton Shell Bed indicate that it was deposited in an estuarine setting during a previous interglacial. Although this traditionally has been regarded as Hoxnian in age (e.g. Catt and Penny, 1966; Edwards, 1978, 1981, 1987), the pollen grains enclosed within the shell bed possess affinities with Ipswichian interglacial floral assemblages from southern England (West, 1969). However, incomplete records of vegetation succession in the stratigraphical record hinder direct correlation between interglacial sites based upon pollen evidence alone (Jones and Keen, 1993). The different altitudinal and stratigraphical positions of the two exposures of the shell bed prompted Catt and Penny (1966) to suggest a dual age, specifically an Ipswichian age for the lower exposure underlying the Skipsea Till and a Hoxnian age for the upper exposure underlying Basement Till. Considerable evidence for glaciotectonic disturbance indicates that the upper exposure probably has been transported by glacial thrusting since its deposition (Edwards, 1978, 1981, 1987; Thistlewood and Whyte, 1993). Although Edwards (1981, 1987) suggests that this took place during the Wolstonian glaciation, he reports that Devensian not Wolstonian (Basement) till overlies the shell bed. More recently, amino acid ratios from the high elevation outcrop of the Speeton Shell Bed indicated that it is probably of Ilfordian interglacial age (Oxygen Isotope Stage 7; Wilson, 1991).

Despite the clear evidence for glaciotectonic disturbance and displacement of the upper exposure, the Speeton Shell Bed contains valuable information on the Quaternary palaeoenvironments of Filey Bay and eastern Yorkshire. Temperate deposits, dating to a former interglacial episode, record estuarine sedimentation at a time when the Vale of Pickering was still open to the sea, a geography that was changed radically some time after the deposition of the Speeton Shell Bed when the emplacement of the Flamborough and Wykeham moraines (referred to locally as the 'Speeton Moraine') blocked the easterly drainage of the proto-Derwent and its tributaries (Valentin, 1957; Penny and Rawson, 1969). The prominent hummocky topography to the south and west of Reighton Sands constitutes part of the Flamborough moraine and documents the ice-marginal stacking of material in response to the intense compressive flow imparted on the North Sea glacier lobe as it flowed onshore during glacial conditions (Valentin, 1957; Straw, 1979b).

Description

The Speeton Shell Bed attains a maximum thickness of a little over 3 m and crops out at two localities. First, between Middle Cliff and New Closes Cliff (TA 147 758), it lies at 27–32 m OD and is sandwiched between Lower Cretaceous Speeton Clay and till, the latter regarded as Basement Till by Lamplugh (1891a), Catt and Penny (1966) and Catt (1977c), but as Skipsea Till or 'Lower Till Series' by Edwards (1981, 1987; Figure 4.23). Second, near Reighton Gap (TA 142 763), it lies at beach level between Kimmeridge Clay and Skipsea Till. Basement Till was originally reported as overlying the Speeton Shell Bed by Lamplugh (1879, 1891a). Because both the sediments and the enclosed fauna show a great similarity, the two exposures traditionally have been regarded as the same deposit, even though the intervening 450 m of cliff has never yielded any further outcrops of the Speeton Shell Bed. Owing to the infrequent exposure of the lower outcrop of the Speeton Shell Bed, the higher outcrop has been used almost exclusively for intensive investigations.

The sedimentology of the higher outcrop was described by Edwards (1987) as comprising 1 m

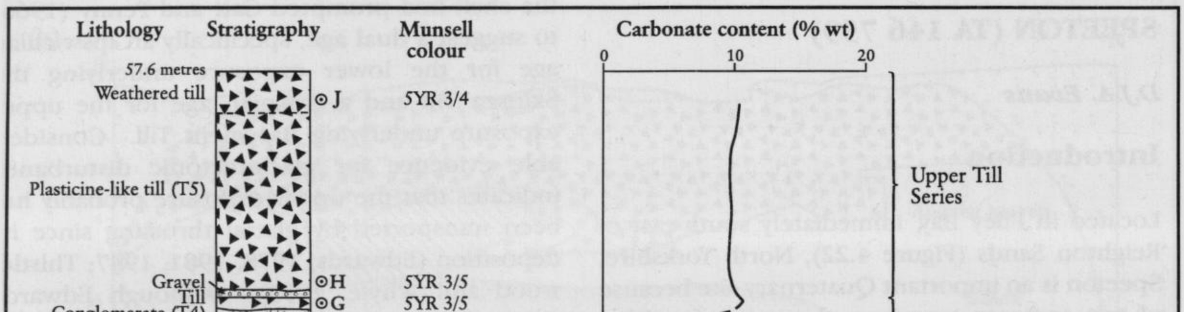

Figure 4.23 Stratigraphical log of the complete Quaternary succession at New Closes Cliff (after Edwards, 1981), showing the relationship between the Speeton Shell Bed and the overlying Devensian Lower and Upper Till Series (Skipsea Till Formation, Evans *et al*., 1995).

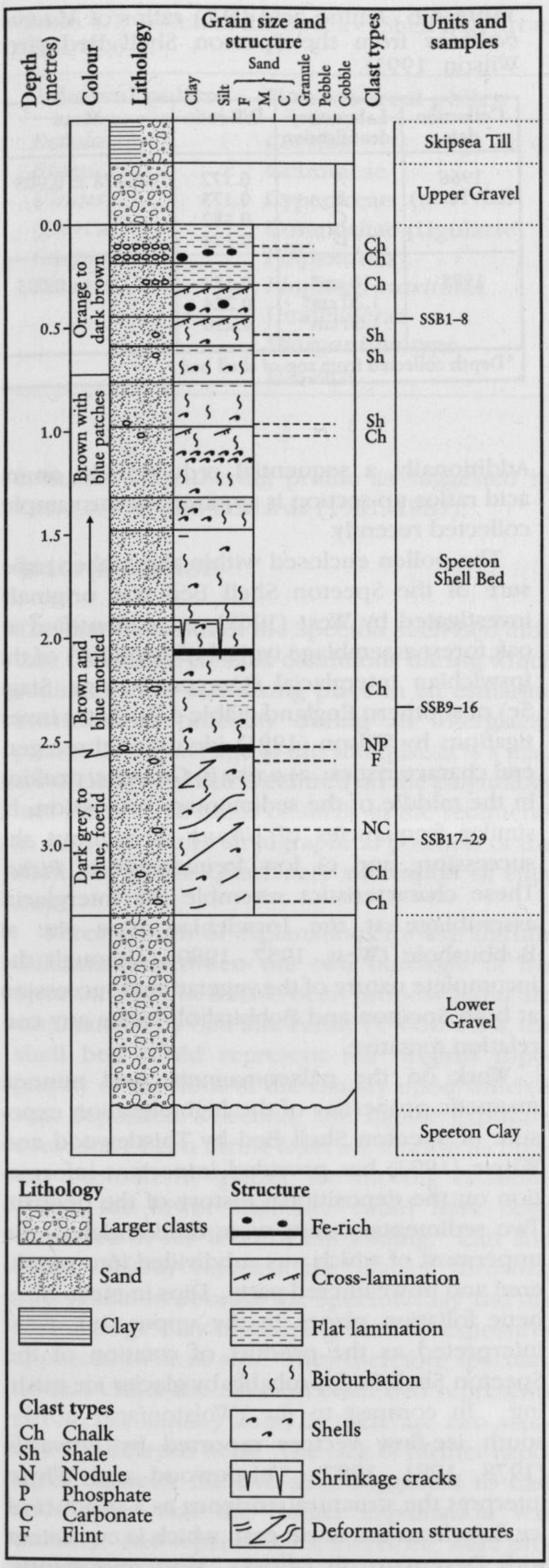

Figure 4.24 Stratigraphical log of the Speeton Shell Bed as exposed between Middle Cliff and New Closes Cliff (after Thistlewood and Whyte, 1993).

of blue-black silty clay, overlain by 1 m of blue-brown silty clay and then 1 m of brownish silt and fine-grained sand. Slightly coarser grain sizes were recorded by Thistlewood and Whyte (1993; Figure 4.24). The colour changes in the Speeton Shell Bed have been interpreted by Catt (1977c) and Edwards (1981, 1987) as the products of weathering. There is some evidence, although not unequivocal as pointed out by Thistlewood and Whyte (1993), that the weathering patterns have been modified by glaciotectonic disturbance in the lower beds. Recognizable sedimentary structures within the shell bed comprise rhythmically bedded flat lamination, ripple cross-lamination and trough bedding with evidence of bioturbation. Overall the bedding dips southwards at approximately 15°. Some large chalk clasts occur in isolation in some beds. Downward-tapering cracks in the central unit of the shell bed are interpreted by Thistlewood and Whyte (1993) as either relict frost cracks or desiccation cracks. Iron-rich layers, probably representing iron pans, also exist in the lower half of the exposure (Figure 4.24). The shell bed is separated from the underlying Speeton Clay by 0.6 m of angular chalk gravel with quartzite erratics, named the 'Lower Gravel' by Thistlewood and Whyte (1993). A similar thickness of angular chalk gravel separates the shell bed from the overlying till, named the 'Upper Gravel' by Thistlewood and Whyte (1993).

Glaciotectonic disturbance of the Speeton Clay and chalk gravel was reported by Edwards (1978, 1981, 1987), who identified from the glaciotectonic structures a former north–south direction of glacier ice flow . This is in contrast to the predominant NE–SW flow directions of the late Devensian glacier ice in this area. The degree of glaciotectonic disturbance in the high-altitude Speeton Shell Bed itself diminishes up section. Specifically, monoclinal folding and thrust planes occur in the lower part of the shell bed and this gives way up-section to minor flexuring. In addition, valves of *Cardium edule* have been dislocated in the lower part of the shell bed but are intact and in life position towards the top. Edwards suggests that the Speeton Shell Bed was compressed and elevated over a vertical distance of 28 m during the glaciotectonic disturbance. The Upper Gravel lying on top of the shell bed is predominantly horizontally bedded, indicating to Edwards (1981, 1987) that it was deposited after glaciotectonic disturbance. Although Wolstonian till had been reported from Speeton by early research (e.g. Lamplugh, 1891a; Catt and Penny, 1966; Catt, 1977c), Edwards (1987) declares that no Wolstonian till directly overlies the shell bed except for a thin streak contained within the Lower Till Series.

Most of the higher exposure of the Speeton Shell Bed contains shells or shell fragments, although Thistlewood and Whyte (1993) point out that the density of shell is low in the beds immediately above and below the frost-desiccation crack horizon. The faunal list as compiled by Lamplugh (1881c) and expanded by Thistlewood and Whyte (1993) is reproduced in Table 4.5 and represents an estuarine assemblage similar to the present-day Humber (Penny and Rawson, 1969; Penny, 1974). The microfauna collected and reported by Edwards (1978, 1987) indicates a slightly colder estuarine environment. Amino acid ratios were obtained on *Macoma balthica* shells by Wilson (1991) and are presented in Table 4.6. Four shells originally collected by L.F. Penny had been coated with resin and, although this was removed, some contamination may have taken place, explaining the lower average ratio of 0.178. A higher average ratio of 0.203 was obtained on freshly collected shells, indicating an appreciably older age.

Table 4.5 Faunal list for the Speeton Shell Bed (after Lamplugh, 1881c; Thistlewood and Whyte, 1993).

Psammobia sp.
Mactra sp.
Cerastoderma edule (L.)
Tellina balthica
Cardium edule
Macoma balthica (L.)
Scrobicularia plana (da Costa)
Scrobicularia piperata
Littorina littorea (L.)
L. rudis
Hydrobia (*Peringia* or *Sabanaea*) *ulvae* (Pennant)
Retusa obtusa (Montagu) var. *pretenuis*
Mytilus edulis (L.)
Utriculus obtusus
Littorina saxatilis (Olivi)
Littorina littoralis (L.)
Balanus crenatus
echinoid spines

Table 4.6 Amino acid (D/L) ratios of *Macoma balthica* from the Speeton Shell Bed (from Wilson, 1991).

Collection date	Laboratory identification	D/L ratio	Mean
1966 (L.F. Penny)	A	0.172	0.178 ± 0.005
	B	0.173	
	C	0.182	
	D	0.184	
1988	50 cm*	0.154	0.203 ± 0.035
	1.20 cm*	0.224	
	1.60 cm*	0.230	

*Depth collected from top of shell bed

Additionally, a sequential reduction in amino acid ratios up-section is apparent in the samples collected recently.

The pollen enclosed within the higher exposure of the Speeton Shell Bed was originally investigated by West (1969), who identified an oak forest assemblage typical of Zone II(f) of the Ipswichian interglacial (Oxygen Isotope Stage 5e) of southern England (Table 4.7). Later investigations by Wilson (1991) identified three general characteristics: a) a rise in *Quercus*, peaking in the middle of the sedimentary succession; b) similar frequencies of *Ulmus* throughout the succession; and c) low frequencies of *Picea*. These characteristics resemble the interglacial assemblage at the Ipswichian type site at Bobbitshole (West, 1957, 1980), although the incomplete nature of the vegetational succession at both Speeton and Bobbitshole make any correlation tentative.

Work on the palaeomagnetic and mineral magnetic properties of the high-elevation exposure of Speeton Shell Bed by Thistlewood and Whyte (1993) has provided important information on the depositional history of the deposit. Two sedimentary units were differentiated, the uppermost of which was subdivided into weathered and unweathered parts. Dips in mean magnetic foliation planes in the upper unit were interpreted as the product of rotation of the Speeton Shell Bed, probably by glacier ice pushing. In contrast to the (Wolstonian?) north–south ice-flow vectors reported by Edwards (1978, 1981, 1987), Thistlewood and Whyte interpret the structural evidence as a product of ice flow from the north-east, which is consistent with Devensian till fabrics. Most importantly, Thistlewood and Whyte conclude that the high-elevation Speeton Shell Bed is not *in situ* and it

Table 4.7 Pollen of the Speeton Shell Bed (from West, 1969).

Arboreal pollen	Non-arboreal pollen
Betula	*Corylus*
Pinus	Gramineae
Ulmus	Cyperaceae
Quercus	Compositae (Ligulatae)
Carpinus	*Filipendula*
Picea	*Plantago maritima*
	Umbelliferae
	Sparganium-type
	Filicales

contains a weathering profile as suggested by Catt (1977c) and Edwards (1981, 1987).

Interpretation

The marine fossils of the Speeton Shell Bed indicate temperate climatic conditions during which sedimentation was taking place in an estuarine environment probably during an interglacial phase. The exact age of this interglacial is a matter of debate, which is centred on the palynology and amino acid ratios of shells in the sediments in addition to the stratigraphical position of the shell bed in the Quaternary succession of Filey Bay.

Three groups of explanations for the altitude differences between the two outcrops of the Speeton Shell Bed have been proposed and are summarized by Catt and Penny (1966). First, the shell bed could represent the original topography of the floor of the estuary upon which it was deposited. Second, the higher exposure could have been thrust from sea level to its present position by glacier ice moving onshore. Third, the lower exposure could have been emplaced at sea level by landsliding. Catt and Penny (1966) rejected the glacier thrusting interpretation because the Speeton Clay and the Kimmeridge Clay underlying the two exposures appeared to be *in situ*. They therefore speculated that either the Speeton Shell Bed represents the former estuary floor, or there are two separate fossiliferous beds. The lack of further exposures between the two sites suggested to Catt and Penny that the former explanation was unlikely. Two separate ages, therefore, were proposed by Catt and Penny based upon stratigraphical associations with tills of apparently different ages. Specifically, the upper Speeton Shell Bed exposure appeared to lie stratigraphically below Basement Till, indicating a Hoxnian or earlier interglacial age. Based upon the similarity of the molluscs at Speeton with those in Hoxnian deposits at Kirmington (Reid, 1885), Catt and Penny confirmed Melmore's (1935) assignment of a Hoxnian age for the higher Speeton Shell Bed. The altitudinal similarity of the lower Speeton Shell Bed and the Sewerby interglacial beach, in addition to its capping by Skipsea Till, led Catt and Penny (1966) to suggest an Ipswichian interglacial age for the lower outcrop.

A Hoxnian age for the upper exposure of the shell bed was supported by Edwards (1978), who ascribed the glaciotectonic disturbance in the sediments to Wolstonian glacier ice, even though he did not support the classification of the overlying till as Basement Till. His interpretation was prompted by the fact that the glaciotectonic disturbance did not continue into the Upper Gravel and therefore related to a pre-Devensian (pre-Dimlington) glacial advance. The absence of Basement Till at Speeton prompts a further reassessment of the diachronous nature of the two Speeton Shell Bed exposures as suggested by Catt and Penny (1966); in essence, the Devensian age of the till overlying both exposures indicates a similar age for the low and high elevation shell beds, although the lack of research on the flora and fauna of the low elevation exposure hinders further critique.

The pollen evidence presented by West (1969) and Wilson (1991) possesses affinities with the Ipswichian interglacial assemblage at Bobbitshole, questioning the Hoxnian age classifications proposed through stratigraphical analysis. As Wilson points out, however, the palaeoenvironmental records for the Ipswichian and other interglacials are assembled from fragmentary evidence derived from various sites. The corollary is that evidence of different interglacials could have been grouped incorrectly grouped into single stages. Important sites in this respect are Ilford and Aveley in the Thames estuary, with interglacial deposits that have been equated with the Ipswichian by West (1980) based upon pollen assemblages despite the fact that the evidence of vegetation succession is incomplete. Faunal evidence from these sites does not confirm the correlation with typical Ipswichian assemblages (Stuart, 1976; Sutcliffe, 1976), but, because this evidence is similarly incomplete, Quaternary scientists have begun to

Table 4.8 Correlation of post-Hoxnian events, amino acid ratios and oxygen isotope stages (after Wymer, 1985; Bowen and Sykes, 1988).

Age (ka BP)	Oxygen isotope stage	D/L ratio (Macoma)	Stage
	2		Dimlington
24			
	3	0.085	
59			
	4		
71			
	5a–d		
122			
	5e	0.16	Ipswichian
128			
	6		Wolstonian 3
186			
	7	0.2	Ilfordian
245			
	8		
303			
	9	0.29	Hoxnian

construct a chronostratigraphy based upon amino acid ratios (Bowen and Sykes, 1988). These data have highlighted the greater antiquity of the Hoxnian interglacial, now dated to Oxygen Isotope Stage 9 rather than stage 7, and identified the Ilfordian interglacial at Oxygen Isotope Stage 7 (Table 4.8).

An attempt to date the higher Speeton Shell Bed by Wilson (1991) using amino acid ratios on *Macoma balthica* resulted in the identification of pre-Ipswichian and post-Hoxnian values, prompting the attachment of an Ilfordian interglacial age. Stratigraphically, if Basement Till does overlie the Speeton Shell Bed (Lamplugh, 1879, 1891a; Catt and Penny, 1966) and/or the glaciotectonic disturbance of the shell bed is pre-Devensian (Edwards, 1978, 1981, 1987), the Basement Till and glaciotectonic features equate to Isotope Stage 6 or the 'Wolstonian' glaciation. However, amino acid D/L ratios of 0.057 on *Macoma balthica* shells from the Basement Till at Dimlington indicate a late Devensian age (Eyles *et al.*, 1994; see Dimlington site report, Chapter 5). Clearly some problems may have arisen from the misidentification of the Basement Till along the east Yorkshire coast, but the age of the Speeton Shell Bed has been placed by Wilson (1991) firmly at an earlier date than the maximum (Wolstonian) age of the till and glaciotectonic structures associated with the displacement of the shell bed. A Wolstonian age for the glacial thrusting implies that the construction of the Flamborough and Wykeham moraine belts and the blocking of the lower Vale of Pickering by ice-marginal stacking of thrust blocks could have been initiated as early as Oxygen Isotope Stage 6.

The frost or shrinkage crack horizon, with its associated reduction in shell material, identified by Thistlewood and Whyte (1993), possibly records a period of sea-level lowering during the deposition of the Speeton Shell Bed, although the exact climatic implications are uncertain. The sequentially younger amino acid ratios reported by Wilson (1991) provide ages for samples from above the crack horizon ranging from Ilfordian to Ipswichian. Although some importance was attached to this by Thistlewood and Whyte (1993), who incorrectly assumed that the younger sample only was taken from above their shrinkage crack horizon, there is a strong possibility that the upper sample has been contaminated by the weathering profile within which it was located; amino acid racemization is strongly controlled by the temperature history of the enclosing sediments. The weathering profile at the top of the Speeton Shell Bed is thought to have been produced during the Ipswichian interglacial (Catt, 1977c; Edwards, 1981, 1987), an assumption based solely on its stratigraphical position beneath glaciotectonically undisturbed 'Upper Gravel' and Devensian (Lower Series) till.

Conclusions

More than 100 years since its discovery, the Speeton Shell Bed remains central to reconstructions of late Quaternary events on the Yorkshire coast, specifically the critical post-Hoxnian to pre-Ipswichian time period. Because of its small exposures, the stratigraphical context of the Speeton Shell Bed has been difficult to elucidate and this has led to its exclusion from the most recent correlation of Quaternary deposits in the British Isles (Bowen, 1999). The application of new techniques in Quaternary science, particularly amino acid geochronology, has confirmed the importance of the Speeton Shell Bed as a rare interglacial deposit probably dating back to approximately 200 000 years BP when sea levels may have been 15 m higher than present (Wymer, 1985). Based upon the discussion presented above, the following conclusions can be made about the high-elevation Speeton Shell Bed.

1. It is an estuarine deposit containing a rich molluscan fauna indicative of temperate

(interglacial) conditions, although microfaunal evidence suggests temperatures slightly cooler than present. As such it documents a palaeogeography characterized by a tidal Vale of Pickering, when the proto-Derwent flowed along the vale to the North Sea.

2. It has been disturbed glaciotectonically in its lower layers, documenting a glacial thrusting episode of pre-Devensian (Wolstonian) age. The outcrop is not *in situ* but rather has been transported as a raft by glacial thrusting.
3. It is capped by undeformed chalk gravel (Upper Gravel), which in turn is overlaid by till (Lower Till Series or Skipsea Till Formation), more recently regarded as Devensian in age.
4. It has been weathered, particularly in its upper layers, probably during the Ipswichian interglacial (stratigraphically constrained by conclusions 2 and 3).
5. It contains evidence of a hiatus in the form of frost or shrinkage cracks associated with a horizon of sparse shell material. This indicates a complex depositional history but the palaeoclimatic implications are unknown.
6. Although previously it has been assigned to the Hoxnian interglacial on stratigraphical grounds and it contains a pollen assemblage similar to those of other Ipswichian sites, amino acid ratios indicate that it probably dates to Oxygen Isotope Stage 7 (Ilfordian interglacial).

Rather less is known about the lower exposure of the Speeton Shell Bed at Reighton Gap. An Ipswichian age was suggested by Catt and Penny (1966) based upon its altitudinal similarity with the Sewerby interglacial beach and the fact that it lay beneath Devensian till, but without further information on the stratigraphy and the amino acid geochronology any age differentiation is speculative. The possibility that it constitutes the undisturbed lateral equivalent of the glacially rafted, high-altitude outcrop of the Speeton Shell Bed is still viable.

SEWERBY (TA 198 683)

D.J.A. Evans

Introduction

The cliffs at Sewerby, a village to the north of Bridlington on the east Yorkshire coast (Figure 4.25), comprise a sequence of sediments containing evidence of environmental changes since the last interglacial and possibly longer. The exposure lies in the lee of a buried chalk cliff, which is capped to the north by hummocky topography of the 'Flamborough Head moraine' (Lamplugh, 1891a; Farrington and Mitchell, 1951), although most of the exposure is permanently obscured by landslide debris. First reported by Reid (1885) and then investigated more thoroughly by G.W. Lamplugh (1887, 1889, 1891b), the site is of national and international significance owing to: (a) the occurrence of beach deposits dating to the Ipswichian Interglacial of 132–122 ka; (b) a sequence of overlying sediments that document the fall in sea level and decline in temperatures at the beginning of the last (Devensian) glacial cycle; and (c) evidence of the advance of ice into the area during the Dimlington Stadial (Catt and Penny, 1966; Catt, 1987b, c). Of further importance with respect to long-term sea-level changes is the buried chalk cliffline and associated marine platform (Figure 4.26), which has been traced from Sewerby (where the modern cliff intersects the buried cliff) inland to Great Driffield and then southwards to the Humber estuary (Crofts, 1906; Crofts and Kendall, in Kendall and Wroot,

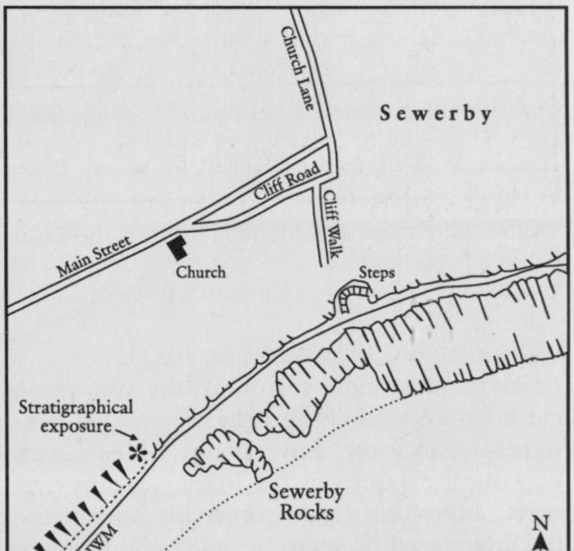

Figure 4.25 Local site map for the Sewerby stratigraphical exposure.

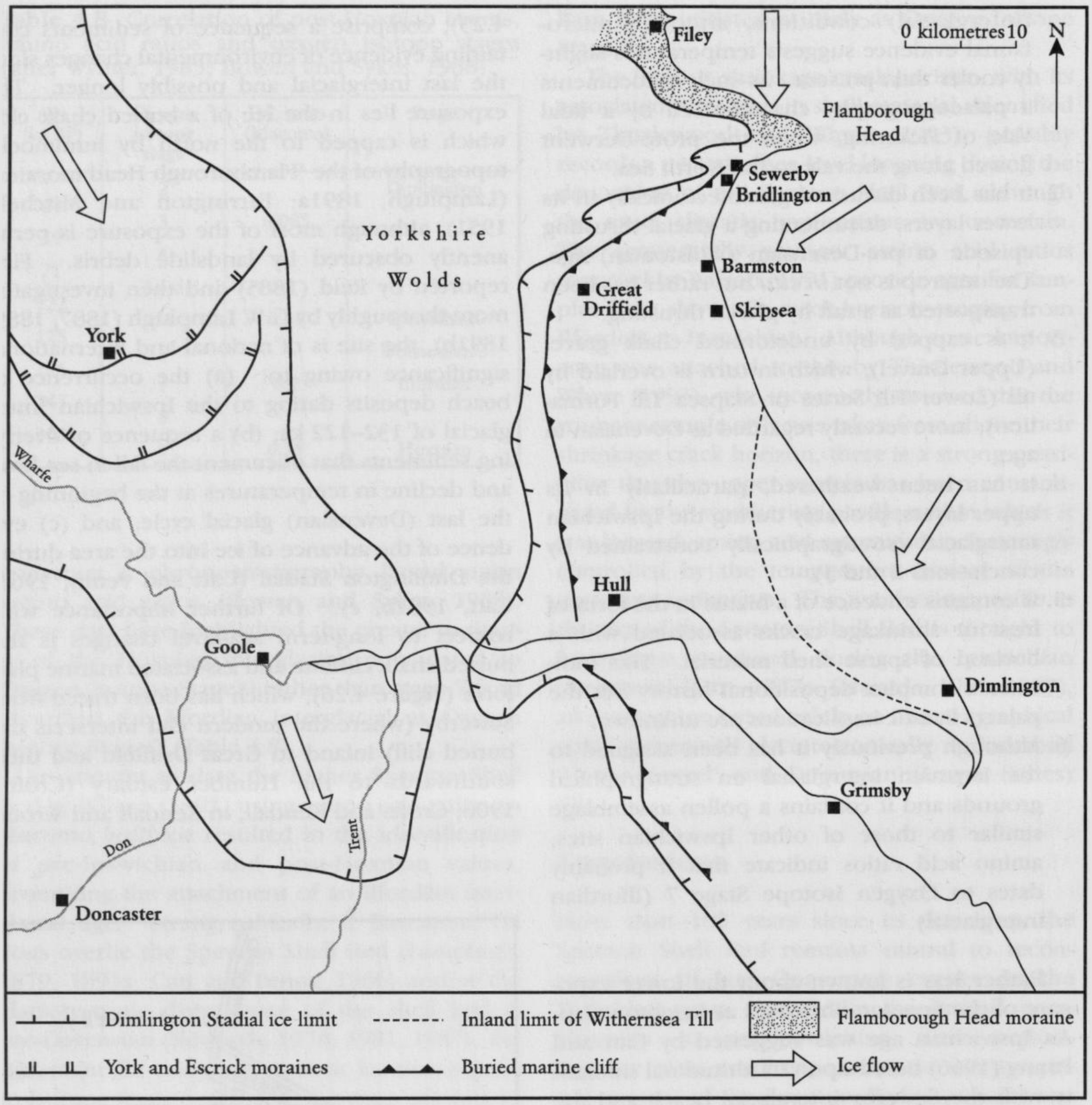

Figure 4.26 Map of Holderness showing the location of the buried cliffline and other Quaternary landforms.

1924; Newton, 1925; Valentin, 1957).

Some uncertainty surrounds the stratigraphical relationship between the interglacial beach deposits and the lowest and oldest glacial deposit, the Basement Till, in the Sewerby exposure. Lamplugh (1890) originally documented the interglacial beach to lie below the Basement Till but this was later reassessed by Catt and Penny (1966), who suggested that the beach lay between the Basement Till and the overlying Devensian deposits. This implied that the Basement Till documented a pre-Ipswichian glaciation. A more recent study by Eyles *et al.*, (1994) has re-instated Lamplugh's original interpretation, suggesting that both the Basement Till and the overlying glacial sediments are post-Ipswichian in age and that the tills and their associated intervening stratified sediments record surging by the North Sea lobe of the British Ice Sheet. Eyles *et al.*, (1994) also re-interpreted the Sewerby gravels, originally regarded as proglacial outwash (Lamplugh, 1884a, 1887; Catt, 1987c), as raised beach deposits dating to deglaciation.

Description

The buried marine cliff and platform at Sewerby (Figure 4.27) are cut into the dip slope of the Chalk, with the platform dipping away from the cliff at a gradient of between 2 and 3 m km^{-1}. The platform is also incised up to 40 m below present sea level by narrow channels, which were cut rapidly in response to falling sea level at the onset of subsequent glaciation (Crofts and Kendall, in Kendall and Wroot, 1924; Valentin, 1957).

The complex till classification scheme that has arisen for east Yorkshire over the last century or more is reviewed in the Dimlington GCR site report (Chapter 5). The lowest and oldest till at Sewerby, the Basement Till (Lamplugh, 1881a, 1882, 1884a, 1890), is only temporarily exposed at a few localities along the Holderness coast, the most extensive exposure being at Dimlington. Described by Bisat (1939, 1940) as the 'Basement Clay', it is part of the Basement Series of Catt and Penny (1966) and comprises a clay-rich, matrix-supported diamicton of a dark grey-brown colour, with green tinges and rafts and smudges of shelly, glauconitic sand. Carruthers (1948) thought these inclusions to be of Bridlington Crag, which includes dinoflagellates and derived pollen indicating a Pastonian age, >1600 ka (Lamplugh, 1884b; Catt and Penny, 1966; Reid and Downie, 1973; Gibbard *et al.*, 1991). Based upon borehole evidence collected by Lamplugh (1919), Catt and Penny (1966) suggest that the Basement Series is the lowest stratigraphical unit on the east Yorkshire coast, directly overlying the chalk platform. A minimum age of 18 000 years BP for the Basement Till is provided by radiocarbon dates on peat overlying the till at Dimlington (Penny *et al.*, 1969). Temporary exposures on the foreshore at Sewerby, reported by Catt and Penny (1966), revealed weathered Basement Till overlain by

Figure 4.27 The buried marine cliff and platform at Sewerby. From this location the chalk cliff (outlined by broken lines) trends inland. Stratigraphical units visible in this typical view include: (A) the 'rainwash' or colluvium; (B) the aeolian sand; (C) the chalk rubble; (D) the 'Drab Till' or Skipsea Till Formation; and (E) the Sewerby Gravels. (Photo: J. Rose.)

chalk gravels similar to the Ipswichian beach gravels (Figure 4.28). This prompted Catt and Penny (1966) and Catt (1987c) to suggest a pre-Ipswichian age for the Basement Till.

The interglacial beach at Sewerby is up to 1.5 m thick and comprises rounded chalk pebbles with occasional flints and erratic lithologies (Figure 4.28). It contains marine molluscs and a relatively rich faunal assemblage (Table 4.9), including straight-tusked elephant (*Palaeoloxodon antiquus*) and hippopotamus (*Hippopotamus amphibius*; Lamplugh, 1891a; Boylan, 1967). Some of these species persist through the two overlying sedimentary units, although hippopotamus is found only within the beach deposit.

Overlying the beach and banked up against the buried cliff base is up to 1.5 m of a clay and chalk slope deposit described as 'clayey chalk-wash' by Lamplugh (1887) and 'rainwash' by Catt and Penny (1966). This deposit includes terrestrial molluscs and vertebrate remains (Table 4.9; Lamplugh, 1891a; Boylan, 1967).

Lying over the 'rainwash' is a sand deposit, referred to as 'blown sand' by Lamplugh (1887) and Catt and Penny (1966), which occurs as a depositional wedge backed up against the buried cliff and thickens to 8 m at the cliff face. Bedding observed within the sand by Lamplugh (1887) dipped towards the cliff. Although the sand is predominantly well sorted it also includes occasional angular chalk clasts. This deposit contains a restricted vertebrate fauna (Table 4.9), all of which occur also in the interglacial beach shingle. An absolute age of 120 840 ± 1 820 years BP has been obtained for the sand by Bateman and Catt (1996), using luminescence dating techniques.

A clast-supported diamicton, comprising angular chalk and flint clasts with minor sand and silt beds and referred to as 'Chalk rubble' by Lamplugh (1887), occurs as a thin drape (<30 cm thick) on the buried cliff top and then thickens to a maximum of 6 m in a south-westerly direction beyond the former cliff line. This deposit contains cold-climate terrestrial molluscs as reported by Lamplugh (1903). The silt beds possess a similar minerological signature to silts within the overlying Drab–Skipsea Till and have been equated by Catt *et al.*, (1974) with a similar deposit beneath Skipsea Till near Hull, which was later dated to 17 500 ± 1600 years BP by Wintle and Catt (1985).

The upper and most recent till at Sewerby, the Drab Till (referred to more recently as the Skipsea Till by Madgett and Catt (1978) and the Skipsea Till Formation by Evans *et al.* (1995)), is the most extensive glacial deposit on the east Yorkshire coast. It is a matrix-supported diamicton of variable structure and colour, but is predominantly dark greyish-brown with localized streaks of chalk, red sandstone and black shale, the general appearance ranging from massive and structureless to laminated with recognizable

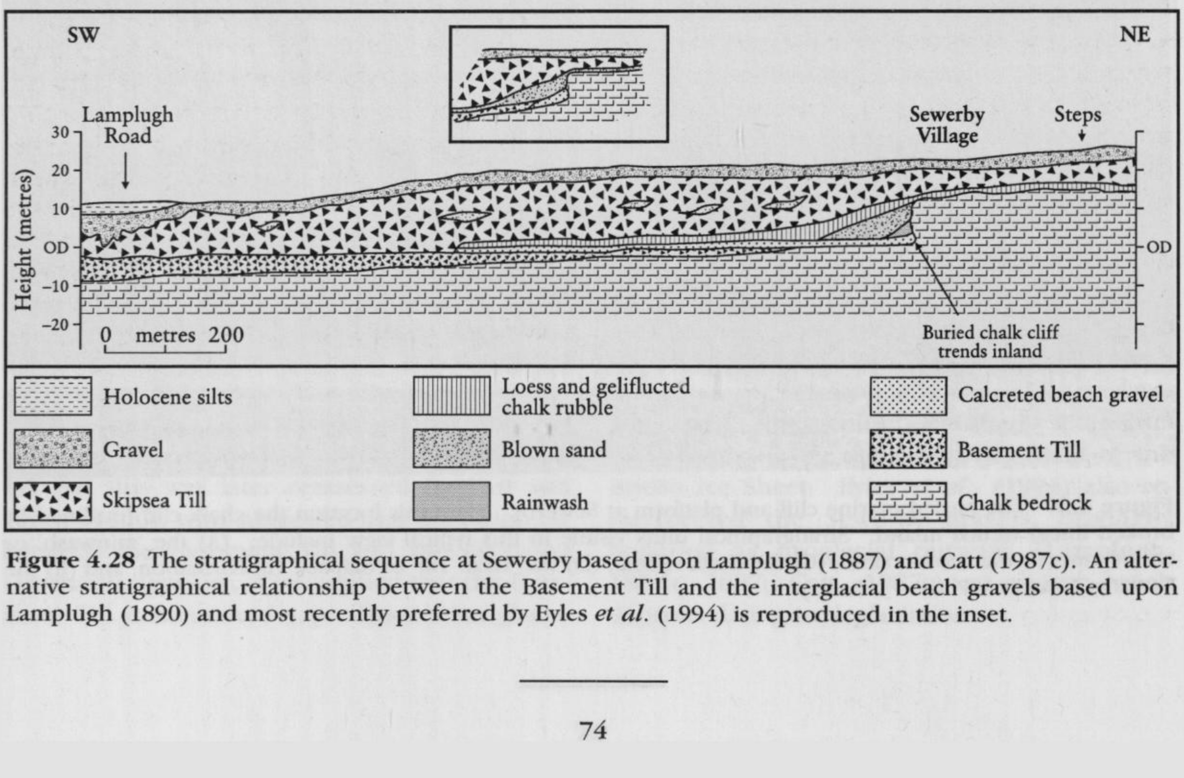

Figure 4.28 The stratigraphical sequence at Sewerby based upon Lamplugh (1887) and Catt (1987c). An alternative stratigraphical relationship between the Basement Till and the interglacial beach gravels based upon Lamplugh (1890) and most recently preferred by Eyles *et al.* (1994) is reproduced in the inset.

Table 4.9 Faunal list for the Sewerby sedimentary units (after Lamplugh, 1891b; Boylan, 1967; Catt, 1987c).

	Ipswichian beach gravel	Colluvium	Aeolian dune sand
Mammalia			
Crocuta crocuta (hyaena)	•		•
Ursus (bear)		•	
Palaeoloxodon antiquus (straight-tusked elephant)	•		•
Didermoceros hemitoechus (narrow-nosed rhinoceras)	•		•
Hippopotamus amphibius (hippopotamus)	•		
Megaloceros giganteus (giant deer)		•	
Bison cf. *Priscus* (bison)	•	•	•
Arvicola terrestris (water vole)		•	
Mollusca			
Littorina littorea L.	•		
Ostrea edulis L.	•		
Mytilus edulis L.	•		
Purpura lapillus L.	•		
Pholas sp.	•		
Saxicava sp.	•		
Helix hispida L.		•	
Helix pulchella Müll		•	
Pupa marginata Drap.		•	
Zua subcyclindrica L.		•	

fold structures (Eyles *et al*., 1994; Evans *et al*., 1995). The colour differences reflect the various source areas of the erratics transported by the North Sea lobe of the British Ice Sheet after its component ice-streams travelled down the Tees valley and along the north-east English coast from Scotland and then over the marine sediments of the North Sea Basin before overriding the chalk and limestone on the Yorkshire coast (Catt and Penny, 1966; Madgett and Catt, 1978; Edwards, 1981; Catt, 1991b). The Skipsea Till also contains numerous sand and gravel lenses, which are either *in situ* (intraformational) and possess concave-up lower boundaries and flat upper boundaries, or are heavily folded and faulted and in places attenuated into smudges (Evans *et al*., 1995; Benn and Evans, 1996).

The stratigraphical exposure at Sewerby is capped by an extensive gravel unit comprising horizontally bedded, massive and imbricated clasts with predominantly discoid and oblate shapes (Eyles *et al*., 1994). Named the 'Sewerby Gravels' by Dakyns (1879, 1880), Lamplugh (1884a, 1887) and Catt and Penny (1966), this unit was observed by Lamplugh (1881a) to include freshwater silts and ice-wedge casts at a location now hidden behind the sea wall at Bridlington. Similar laminated silts and ice-wedge pseudomorphs have been reported from a coarsening upwards sequence of sediments overlying the Skipsea Till at Barmston (Bridger, 1977; Evans *et al*., 1995), which are regarded as correlative with the Sewerby Gravels by Eyles *et al*., (1994).

Interpretation

The stratigraphical position and age of the Basement Till has become a controversial issue in the Quaternary geology of east Yorkshire. A post-Ipswichian age was indicated by the stratigraphy of Lamplugh (1890), but short-lived exposures on the foreshore in the early 1960s led Catt and Penny (1966) to conclude that the Basement Till lay under the Ipswichian beach and therefore documented a pre-Ipswichian glacial event. Based upon amino acid ratios on shells in the Basement Till at Dimlington that indicate a Late Devensian age, Eyles *et al*., (1994) suggest that the lower (Basement) till at Sewerby also must date to the last glaciation. This has implications for the glacial sequence at Dimlington, because the Basement Till there would indicate an initial Devensian glacier advance prior to 18 000 years BP. In interpreting the genesis of the Holderness tills, Eyles *et al*., (1994) have revived the ideas of Lamplugh (1881b, 1911), who suggested that they originated by the subsole deformation of offshore marine muds and may record surging behaviour by the North Sea glacier lobe.

The changing palaeoenvironmental conditions at Sewerby can be reconstructed by using the faunal remains found within the individual sedimentary units (Lamplugh, 1891b; Boylan, 1967). These are particularly valuable in the interglacial beach and the three overlying units deposited before the Skipsea Till glacier advance. The faunal remains enclosed within the beach gravels, particularly elephant and hippopotamus, are clearly interglacial. Hippopotamus is particularly informative, because its occurrence in the British Quaternary stratigraphy is indicative of the Ipswichian Interglacial of 132–122 ka (Oxygen Isotope Stage 5e) (Jones and Keen, 1993). The interglacial fauna continues throughout the overlying 'rainwash' and sand units, indicating the continuation of warm conditions but changing depositional environments.

The 'rainwash' was interpreted by Lamplugh (1888) and Catt and Penny (1966) as a slope deposit produced by gradual erosion of the chalk cliff by overland flow and minor mass movement processes. The deposit has the characteristics typical of colluvium, materials deposited on slopes by a combination of runoff and mass movement. Interdigitation of the colluvium and the beach gravels indicates that the storm beach was incorporating chalk clasts by the constant erosion of the bedrock cliff during the high sea-level stand of the last (Ipswichian) interglacial. Owing to the fact that colluvium was removed from the cliff base by storm waves during the deposition of the underlying beach gravels, the survival of the colluvium was interpreted by Lamplugh (1887) and Catt (1987c) as an early stratigraphical indicator of declining sea level. Catt (1987a) further speculated that the colluvium and overlying blown sand equates to Oxygen Isotope Stages 5d–5a.

The banking of sand up against the cliff is interpreted as further firm evidence for the fall in sea level in the region. Lamplugh (1887) suggested that the bedding within the well-sorted sand indicated a wind-blown origin and that the sediment accumulated as a dune, initially in front of the cliff and later overtopping it. Further analyses by Catt *et al.* (1974) verified an aeolian origin. The dominance of aeolian processes at this time is also indicated by the polished surface of the chalk cliff face, which Lamplugh (1887) interpreted as the product of sand-blasting. The age of 120 840 ± 1820 years BP reported by Bateman and Catt (1996) lends support to the suggested Ipswichian interglacial age for the underlying beach deposits.

Lamplugh's (1887) 'chalk rubble' is interpreted as a gelifluction deposit produced by slow mass movements in a periglacial climate, as indicated by the angularity of clasts and the cold-climate terrestrial molluscs (Lamplugh, 1903). Silt layers within the rubble are interpreted as loess by Catt *et al.* (1974), who additionally used its mineralogical similarity to the silts in the overlying Skipsea Till to suggest a derivation from the outwash plains in front of the advancing glacier ice. The comparison with silts from a similar deposit near Hull dated at 17 500 years BP, if valid, suggests that there is a 100 000 years depositional break between the aeolian dune sands and the gelifluction material (Catt *et al.*, 1974; Catt, 1987c).

The Drab–Skipsea Till records the advance of the North Sea lobe of the last British Ice Sheet, dating to the Dimlington Stadial (see Dimlington site report, Chapter 5). The varied lithologies represented in the erratic suites of the till reveal a complex provenance for the debris load of the ice sheet (Madgett and Catt, 1978). This includes eastern Scottish, northern English and some Scandinavian lithologies, in addition to the offshore muds of Quaternary age and older. Early interpretations by Lamplugh (1911) suggested that the tills of the Yorkshire coast resembled the subglacially deformed sediments observed at modern arctic glaciers prone to surging, but Carruthers (1948) preferred a melt-out origin. Lamplugh's ideas have been reinstated by Eyles *et al.* (1994), who suggest that the extensive glaciotectonic faults and folds and smeared inclusions within the tills document subglacial deformation of pre-existing sediments at the margin of a surging glacier lobe. A deformation origin is also preferred by Evans *et al.* (1995), who interpret the sand and gravel lenses in the Skipsea Till as the products of subglacial meltwater drainage events that punctuated periods of subglacial deformation of pre-existing sediments by the onshore-flowing North Sea glacier lobe. Comprehensive assessments of the Skipsea Till for the whole Yorkshire coast and its implications for former glacier dynamics can be found in Bisat (1939, 1940), Catt and Penny (1966), Madgett and Catt (1978), Catt and Madgett (1981), Boulton and Dobbie (1993), Eyles *et al.* (1994) and Evans *et al.* (1995).

For a long time regarded as the outwash from the receding Dimlington glacier margin

(Lamplugh, 1884a; Catt, 1987c), the Sewerby Gravels have recently been re-interpreted as the products of coastal beach processes by Eyles *et al.* (1994). A marine origin was suggested originally by Lamplugh (1884a) and the reconciliation of fluvial versus marine interpretations of other sand and gravel deposits along the Yorkshire coast has remained problematic. If the Sewerby Gravels are marine beach deposits, they document a glacio-isostatically higher sea level during glacier recession. The fact that the North Sea lobe would have glacio-isostatically depressed the crust is incontrovertible, but the penetration of the sea into this area of the North Sea Basin and the flooding of depressed land surfaces during early deglaciation, when global sea levels were up to 100 m lower, has not been demonstrated by available sea-level records for the region (Lambeck, 1995). Lamplugh (1884a, 1891a) concluded that all of the evidence suggested a glaciofluvial origin for the Sewerby Gravels, probably in deltas deposited at the margins of a proglacial lake dammed on the Holderness coastal plain by the receding ice margin. This implies that the finer-grained sediments that crop out farther south are interpreted as the distal, deep-water equivalents of the Sewerby Gravels. The ice-wedge pseudomorphs that occasionally are exposed in the Sewerby Gravels possibly indicate that permafrost conditions prevailed until well after ice recession from the Yorkshire coast, although alternative interpretations of these structures are tenable (e.g. water-escape pipes). Models of sea-level changes during deglaciation have yet to verify the marine origin of the Sewerby Gravels and no systematic sedimentological investigation has been undertaken on the sediments.

The most recently revised correlation of Quaternary deposits in the British Isles (Bowen, 1999) has renamed most of the sedimentary and stratigraphical units discussed above in order to bring the nomenclature in line with standard lithostratigraphical terminology. The Basement Till is now referred to as the 'Bridlington Member', the Ipswichian beach is called the Sewerby Member, the Skipsea Till is the 'Skipsea Member' and the Sewerby Gravels are the 'Flamborough Member'. These members are all part of the Holderness Formation.

Conclusions

Sewerby is a site of considerable national and international value with respect to late Quaternary palaeoenvironmental reconstructions and long-term sea-level change. Specifically, the Quaternary sediments are banked up against and drape a buried marine cliff and associated platform that was cut by marine erosion during previous interglacial climate(s). A gravel beach lying on the platform and possibly overlying an older till documents a sea level slightly higher than present. The beach material and two overlying sedimentary units contain faunal remains diagnostic of the last Ipswichian interglacial, dating from 132 to 122 ka. Slope deposits and dune sands overlying the beach gravels record the fall in sea level at the close of the Ipswichian interglacial, when global sea levels were falling in response to the build-up of continental ice sheets. The onset of cold conditions during the Devensian glaciation is recorded by a gelifluction deposit, which drapes the cliff and the earlier sediments. It is thought that a depositional gap of 100 000 years exists between the deposition of the dune sand and the gelifluction deposit. The latter is truncated by the Skipsea Till (Skipsea Member), which was deposited by subglacial deformation by the North Sea lobe of the British Ice Sheet during the Dimlington Stadial, dated to some time after 18 000 years BP. There is controversy surrounding the interpretation of the uppermost sedimentary unit, the Sewerby Gravels (Flamborough Member), which has been interpreted as glaciofluvial outwash and marine beach deposits.

Further critical work is required at Sewerby on two major themes: (a) the stratigraphical position of the Basement Till (Bridlington Member), specifically its relationship with the Ipswichian beach (Sewerby Member), even though the most recent correlation of Quaternary deposits in the British Isles (Bowen, 1999) regards the Basement Till as Late Devensian; and (b) the genesis of the Sewerby Gravels (Flamborough Member) and their significance with respect to the deglacial sea-level history of east Yorkshire.

KELSEY HILL (TA 239 266)

D.J.A. Evans

Introduction

Excavations during the nineteenth and twentieth centuries around Kelsey Hill, on the northbank of the Humber, have provided extensive exposures through a sediment body known as the 'Kelsey Hill Gravels', an important Quaternary sediment–landform assemblage deposited in association with the margin of the Dimlington Stadial ice sheet in the East Riding of Yorkshire. First reported near Burstwick by Smith (1821) and Phillips (1829), the gravels contain a rich fauna (Prestwich, 1861; Penny, 1963) that has been at the centre of considerable controversy over the origin of the deposits. The stratigraphical position of the Kelsey Hill Gravels, between the Dimlington Stadial age Skipsea and Withernsea tills, suggests that sedimentation was a product of glacier marginal fluctuations, but interpretations of exact depositional environment range from marine to glaciofluvial (Lamplugh, 1925; Penny, 1963; Catt and Penny, 1966; Eyles *et al.*, 1994). Further discussion on the Kelsey Hill Gravels has been provided by Geikie (1877), Reid (1885), Sheppard (1895), Sheppard and Stather (1907), Bisat (1940), Carruthers (1948) and Baden-Powell (1956), highlighting the importance of these controversial sediments in reconstructing the Quaternary glacial history of northern England.

Description

The Kelsey Hill Gravels form a low sinuous ridge up to 15 m high around Kelsey Hill (TA 239 266) (Figure 4.29). Surface exposures and borehole evidence from the vicinity have been used more recently by Eyles *et al.* (1994) to suggest that the Kelsey Hill Gravels actually form a series of parallel ridges trending north–south and that Kelsey Hill constitutes the westernmost of these ridges.

The Kelsey Hill Gravels are described by Catt and Penny (1966) as typically yellowish-brown sands and gravels, including erratics, diamicton balls and lenses of diamicton resembling the Withernsea Till. The current bedding in the sands and gravels document a palaeocurrent from the north. More recently, Eyles *et al.* (1994) have described an outcrop at Mill Hill that displays a coarsening upwards succession from pebbly sand overlain by imbricated, openwork gravels or massive gravels capped by imbricated gravels with a north–south palaeocurrent direction. Diamicton balls occurring throughout the sequence here are ascribed to the underlying Skipsea Till. Eyles *et al.* (1994) report that the Kelsey Hill Gravels form a wedge that thins towards the east, eventually grading into a thin stratified layer between the Skipsea and Withernsea tills. On the eastern flank of Kelsey Hill, the Withernsea Till possesses a sharp erosional contact with the Kelsey Hill Gravels (Figure 4.30), the latter having been glaciotectonized and incorporated as small lenses by shearing into the base of the till.

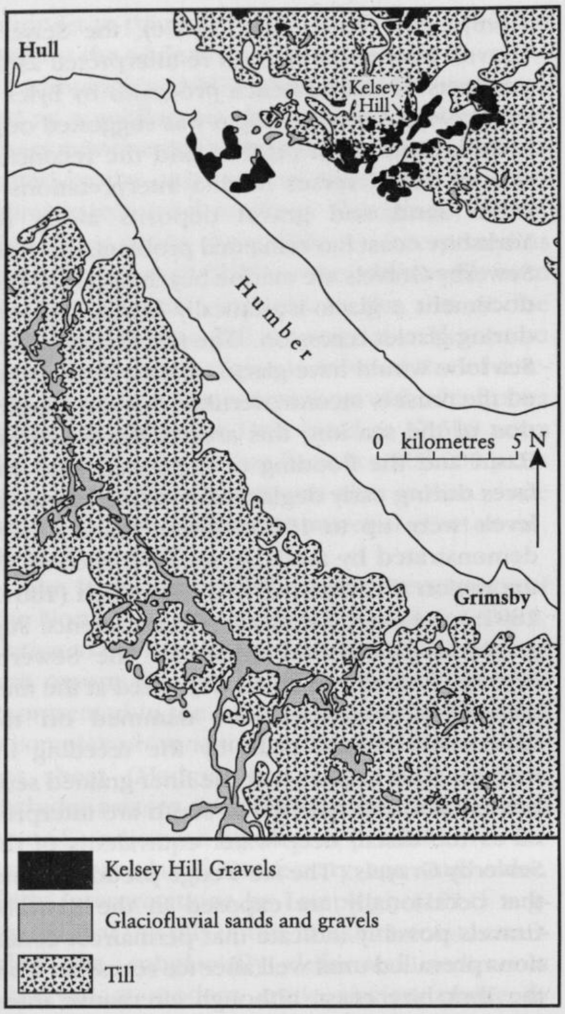

Figure 4.29 Map of the distribution of the Kelsey Hill Gravels and associated landforms and sediments (after Berridge and Pattison, 1994).

Of particular interest is the rich and diverse fossil fauna of the Kelsey Hill Gravels, which includes more than 50 species of marine mollusc in addition to abundant examples of the freshwater bivalve *Corbicula fluminalis* and miscellaneous water-worn vertebrate remains (Penny, 1963). The marine molluscs are littoral and sublittoral types (e.g. *Cardium*, *Mytilus*, *Macoma*, *Ostrea*, *Buccinum*, *Littorina* and *Nassa*) and are temperate in distribution, possessing similar

Figure 4.30 Horizontally bedded Kelsey Hill Gravels truncated by Withernsea Till. (Photo: N. Eyles).

characteristics to Ipswichian interglacial marine fauna. In contrast, the vertebrate remains include cold species such as mammoth, reindeer and bison in addition to interglacial species such as straight-tusked elephant and rhinoceros.

Interpretation

The sinuous nature of the north–south-trending ridge containing the Kelsey Hill Gravels has been used by Catt and Penny (1966) to suggest that it is an esker. This interpretation is supported by the north–south-trending palaeocurrents recorded in the sediments in addition to the numerous peat-filled kettleholes on the ridge surface. Catt and Penny further suggest that the widening and lowering of the esker form to the south represents the subaerial continuation of the esker, where a marginal outwash fan emanated from the subglacial tunnel mouth. Sometime after its deposition the esker was covered by the Withernsea Till, explained by Catt and Penny (1966) as a product of the later stages of drainage of a tiered ice sheet within which the Withernsea Till was the last to melt out.

Early interpretations of the Kelsey Hill Gravels were considerably influenced by the dominance of temperate fossils, resulting in proposals for an interglacial status for the deposits. More recently, Catt and Penny (1966) used the diversity of the fossil assemblage, in addition to the water-worn nature of the vertebrate remains, in the Kelsey Hill Gravels to suggest that they were derived from pre-existing deposits. This is verified to some extent by the fact that the deposit lies between two tills. However, the Devensian age tills on Holderness are rarely shelly (see the site reports for Sewerby, this chapter, and Dimlington, Chapter 5), as would be the case if glaciers had reworked pre-existing shell-rich sediments. The only possible source for shells is the Bridlington Crag, which contains an arctic assemblage rather than a temperate one. Furthermore, the well-preserved nature of the fossils is difficult to reconcile with the normally long distances of travel that are associated with esker production. A further alternative origin is the glacial transport of rafts of Ipswichian sediments from the Humberside embayment (Berridge and Pattison, 1994), an interpretation that explains the lobate arrangement of the Kelsey Hill Gravel outliers and similar glaciofluvial gravel mounds to the south of the Humber. Similarly, Valentin (1957) interpreted the elongate ridge containing the Kelsey Hill Gravels to the north of the Humber as an ice margin, possibly documenting a readvance of the North Sea lobe during its recession from the Dimlington Stadial maximum.

Exposures through the Kelsey Hill Gravels at Mill Hill (Figure 4.31), where the sediments form several distinct ridges, have been used recently by Eyles *et al.* (1994) to propose a marine origin for the sediments. In the southernmost exposures through the proposed outwash fan, they highlight the lack of cross-stratified facies and associated channel fills typical of outwash deposits and propose a correlation of the subaqueously deposited lenses of sediment in the Basement, Skipsea and Withernsea tills at the coast with the inland exposures of the Kelsey Hill Gravels (Figure 4.31). The imbrication and openwork nature of the gravels together with their flat-lying nature are used to support a near-shore, shallow beach-face environment. Further support for this interpretation is: a) the north–south orientation of the 30-km-long ridges containing the Kelsey Hill Gravels, parallel to the trend of the buried interglacial chalk cliffline at Sewerby and the modern coast; and b) the prolific mixed marine and freshwater fossil assemblage. Eyles *et al.* (1994) go on to suggest that the North Sea Lobe surged into a shallow marine embayment, deforming and incorporating parts of the Kelsey Hill Gravels in the base of the Withernsea Till. However, the high sea level required in Eyles *et al.*'s model for the marine flooding of Holderness during the last glaciation is difficult to reconcile with known glacio-eustatic and glacio-isostatic trends, which indicate that the North Sea was dry land until approximately 6500 years BP, well after ice had disappeared from the British landscape (Funnell and Pearson, 1989; Brew *et al.*, 1992; Funnell, 1995; Lambeck, 1995). In addition, the Ipswichian affinities of the marine molluscs and freshwater gastropods indicate that they could not have been living on the Holderness coast during the Devensian glaciation and therefore were probably derived. Nevertheless, the ice-damming of pro-glacial lake water on Holderness, into which the North Sea Lobe could have surged, is a palaeogeographical scenario that requires further testing. The Kelsey Hill Gravels remain central to such palaeogeographical reconstructions; the proliferation of fossil fauna over such a small area remains enigmatic.

Following the proposals of the revised correlation of Quaternary deposits in the British Isles (Bowen, 1999), the Kelsey Hill Gravels should in future be referred to as the 'Mill Hill Member'. The Skipsea Till and Withernsea Till, with which the gravels are juxtaposed, are now labelled the 'Skipsea Member' and 'Withernsea Member' under the same scheme.

Conclusions

Kelsey Hill and surrounding sites contain one of the most enigmatic Quaternary sediment bodies in northern England. Early interpretations invoked marine interglacial conditions to explain the temperate fauna enclosed within the gravels. A more traditional interpretation of the

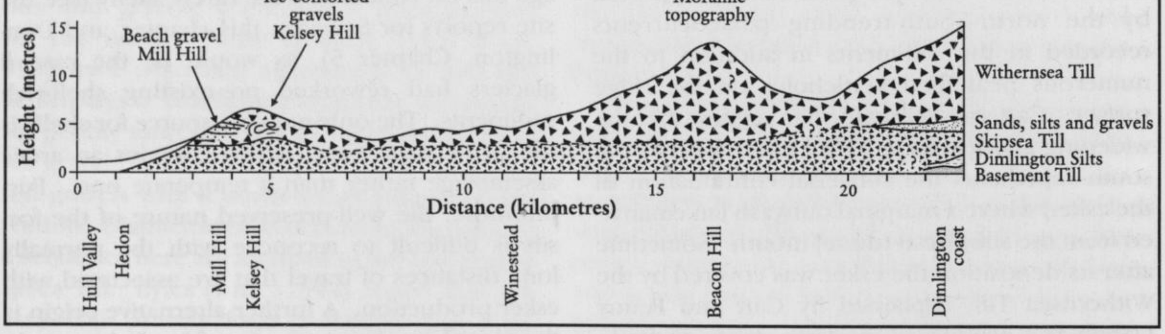

Figure 4.31 Simplified stratigraphical sequence along an east–west transect from Dimlington to Mill Hill, after Eyles *et al.* (1994).

landforms containing the gravels has invoked the deposition of esker ridges grading southwards into a pro-glacial outwash fan, but the sedimentary structures and preservation of the prolific faunal assemblage are difficult to reconcile with such a reconstruction. More recently, the Kelsey Hill Gravels (Mill Hill Member) have been interpreted as marine beach gravels and correlated with deeper water sediments occurring as lenses within the Basement, Skipsea and Withernsea tills (Bridlington, Skipsea, Withernsea members) on the coast. This implies that the gravels were deformed and partially reworked by the North Sea Lobe of the British Ice Sheet as it surged into a shallow marine embayment; the temperate nature of the shells within the gravels, if they are *in situ*, is difficult to reconcile with this interpretation. A further interpretation invokes ice-marginal thrusting of rafts of Ipswichian sediments from the Humberside embayment during advance of the Dimlington Stadial North Sea Lobe, thereby explaining the short distances travelled and localized proliferation of the faunal remains.

HARWOOD DALE MOOR (SE 961 991)

N.F. Glasser

Introduction

Harwood Dale Moor, North Yorkshire, is an important locality for British Quaternary stratigraphy as soil pits at the site have provided evidence for a 'fossil soil' (palaeosol) developed in weathered clays of the Middle Jurassic Estuarine Beds. The palaeosol displays prominent red mottling and is interpreted as having developed under either tropical or subtropical conditions. Although the precise age of the palaeosol remains uncertain the site provides important information on environmental changes and the extent of glaciation in the North York Moors (Figure 4.32).

Ruhe (1956) originally defined the term 'palaeosol' as any soil that has developed on a former land surface, with the intention that the term be applied essentially to 'fossil' (preserved) soils. This definition was amplified by Bronger and Catt (1989) to include non-buried soils that have persisted on a land surface through one or more environmental changes and bear their imprint in the form of relict pedological features

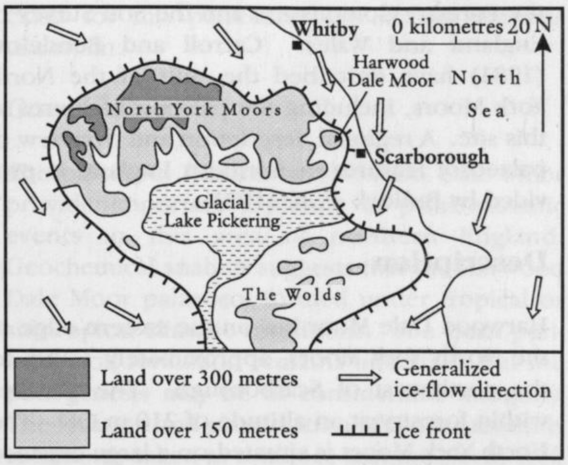

Figure 4.32 The location of Harwood Dale Moor and its relationship to the Late Devensian ice sheet (after Bullock *et al.*, 1973).

that are not in harmony with the present environment. The term 'palaeosol' has, however, been widely used by Quaternary scientists to describe soils that are buried beneath younger sediments, those that are no longer affected by soil-forming processes, or those that are essentially relict features (Lowe and Walker, 1997a; Johnson, 1998). Palaeosols often form under markedly different environmental conditions to those of the present day; by relating the palaeosol horizons to those of modern soils from a range of climatic environments it is possible to make deductions about the environment at the time of soil formation (Dahms, 1998). In particular, palaeosols provide valuable information concerning former climate and vegetation.

Palaeosols are normally identified and described in terms of colour differences, particle-size distribution, clay-mineral composition, organic content and soil macrostructures (Catt, 1986). Recent advances now include the use of soil micromorphology (Kemp, 1985a, 1998; Catt, 1990a; Fitzpatrick, 1993) and mineral magnetic analysis (Thompson and Oldfield, 1986). The use of palaeosols in the reconstruction of Quaternary environments and their significance for Quaternary stratigraphy is discussed by Rose *et al.* (1985a), Catt (1986) and Lowe and Walker (1997a). The classification of palaeosols is outlined by James *et al.* (1998) and by Nettleton *et al.* (1998).

The palaeosol for which Harwood Dale Moor is noted was discovered during soil mapping by the Forestry Commission and the Soil Survey of England and Wales. Carroll and Bendelow (1981) have described the soils of the North York Moors, including the palaeosol features at this site. A regional description and overview of palaeosol features in northern England is provided by Bullock *et al.* (1973).

Description

Harwood Dale Moor lies on the eastern edge of the North York Moors, approximately 13 km to the north-west of Scarborough. The site lies within forestry at an altitude of 210 m OD. The North York Moors is situated on a large expanse of Jurassic rocks rising to over 450 m in altitude, formed mainly of Middle Jurassic (Callovian) marine limestones, sandstones and shales (Wright, 1860; Fox-Strangways, 1892; Wright, 1968, 1977, 1978; Page, 1989). Harwood Dale Moor, on the eastern edge of the moor, is underlain by clays of the Middle Jurassic Estuarine Beds. The Harwood Dale Moor palaeosol itself is a peaty gley overlying weathered clays of the Estuarine Beds. Carroll and Bendelow (1981) classify the soil as a stagnohumic gley with prominent mottling in the Bg horizon. The mottles are reddish-brown in colour (Munsell Colour 2.5 YR and 10 R) and up to 15 cm in diameter. The mottles are so intense that they form the dominant colour. Chemically, the mottles contain crystalline goethite and haematite. The morphology and mineralogy of the iron compounds in the red mottled clays resembles plinthite, a red mottled clay common in tropical regions where there is a marked wet and dry season (Bullock *et al.*, 1973). The precise extent of the mottling is uncertain, although this type of soil appears to cover large areas of the North York Moors plateau (Carroll and Bendelow, 1981).

Interpretation

Palaeosols are relatively abundant throughout Britain and the significance of the Harwood Dale Moor palaeosol lies in its composition, stratigraphical context, and in the debate about the location of the Late Devensian ice margin in this area. In particular the preservation of an interglacial soil has implications for the extent to which the North York Moors escaped glaciation during the Late Devensian. It is a widely held belief that this area escaped glacierization in the Dimlington Stadial owing to its relatively high altitude (Jones and Keen, 1993). Thus, although similar palaeosol features may have existed throughout this area of northern England, many have been removed by glacial erosion. The remnants of this episode of pedogenesis are commonly assumed to survive only in areas that escaped glacierization, but also it is possible that they survive in areas simply where glacial erosion was ineffective. Similar preglacial landscape remnants exist in north-east Scotland, where Pliocene and early Pleistocene weathering mantles also are known to have escaped the effects of glaciation (Fitzpatrick, 1963; Sugden, 1968, 1989; Hall, 1985, 1991; Hall and Sugden, 1987; Hall and Mellor, 1988; Hall *et al.*, 1989; Ballantyne, 1994). The survival of these Scottish weathering covers owes much to the selectivity of glacial erosion and to the basal thermal regime of the ice sheet in this area (Sugden, 1968; Clapperton and Sugden, 1977; Hall and Sugden, 1987; Sugden *et al.* 1992). Patches of former weathering mantles have been related to cold-based zones beneath the former ice sheets in topographically suitable locations (Hall and Sugden, 1987; Glasser and Hall, 1997). Modelling studies have shown that the favoured location for the survival of a former weathering mantle is on upland and plateau areas where rates of ice flow are generally low and the ice is cold-based (Glasser, 1995). This raises the intriguing possibility that the palaeosol at Harwood Dale Moor is in fact an isolated remnant of a previously more widespread soil cover across the North York Moors that was preserved beneath cold-based ice.

The palaeosol features at Harwood Dale Moor also make an interesting comparison with other palaeosols in Britain. These include palaeosols formed under temperate climatic conditions such as the Valley Farm Soil (Rose *et al.*, 1978; Kemp, 1985b; Whiteman, 1990) and those formed under intensely cold conditions such as the Barham Soil (Rose and Allen, 1977; Allen, 1983; Rose *et al.*, 1985b). These palaeosols appear to have a marked concentration in the south and east of Britain. They are particularly developed on river terrace gravels of the ancestral Thames and its tributaries, where they form important stratigraphical markers (Bridgland, 1994). Palaeosols are generally rare in northern England, although they occur in isolated pockets within the Lake District (Boardman, 1985c).

The red mottling in the Harwood Dale Moor soil is not characteristic of any geographically or stratigraphically adjacent geological formation and therefore must be regarded as a true pedological feature (Carroll and Bendelow, 1981). Red mottles previously reported in Britain are generally less concentrated and are confined to plateau drift in Hertfordshire, the Chilterns and Berkshire (Bullock *et al.*, 1973). Together with other pedological features in North Yorkshire, Bullock *et al.* (1973) have suggested that the Harwood Dale Moor palaeosol resembles those found in the modern tropical and subtropical areas where there is a marked wet and dry season. As there is currently no such distinct demarcation between wet and dry seasons in Britain, it seems reasonable to assume that the Harwood Dale Moor soil developed under a different climatic regime and therefore represents a true palaeosol. No independent dating control exists for this palaeosol, and its age remains uncertain.

Conclusions

The palaeosol features at Harwood Dale Moor provide important evidence of palaeoclimatic events in this area of northern England. Geochemical analysis suggests that the Harwood Dale Moor palaeosol formed under tropical or subtropical climatic conditions. The exact period of soil formation remains uncertain, but the pedogenesis may be of considerable antiquity. The location and preservation of the palaeosol is commonly taken as evidence that the North York Moors lay outside the maximum limits of the Dimlington Stadial ice sheet, but there also is the possibility that the palaeosol survives owing to selective erosion by the former ice sheet.